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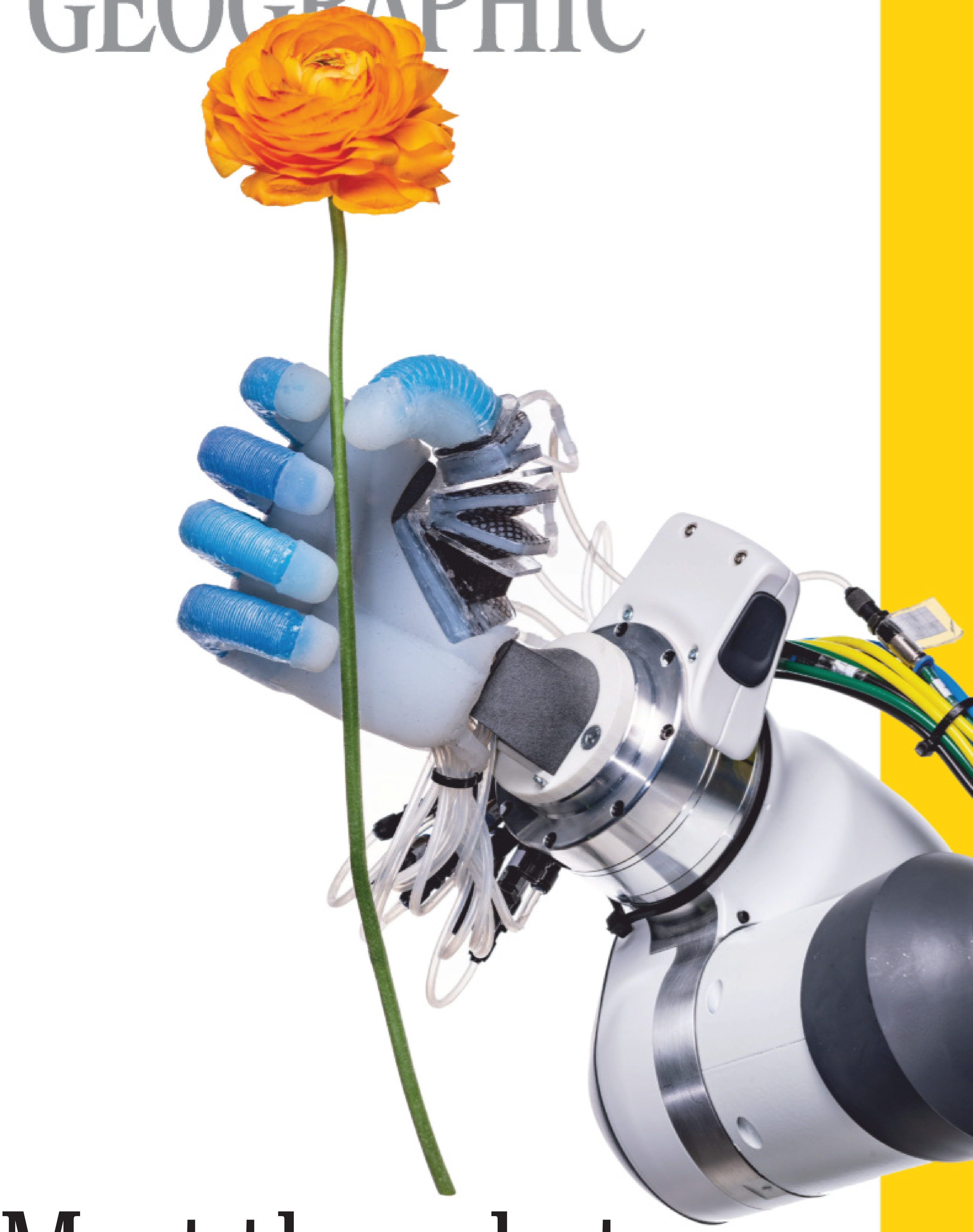
NATIONAL GEOGRAPHIC



Meet the robots

Will smart machines make
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NATIONAL GEOGRAPHIC | FURTHER

SEPTEMBER 2020

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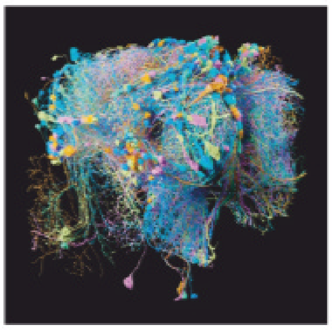

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The new kind of robot isn't like C-3PO of *Star Wars* fame. It's far from human—but still smart, adept, and mobile. It's designed to "live" and work with people. And it's migrating steadily into daily life, in jobs ranging from stocking warehouse shelves to arranging flowers.
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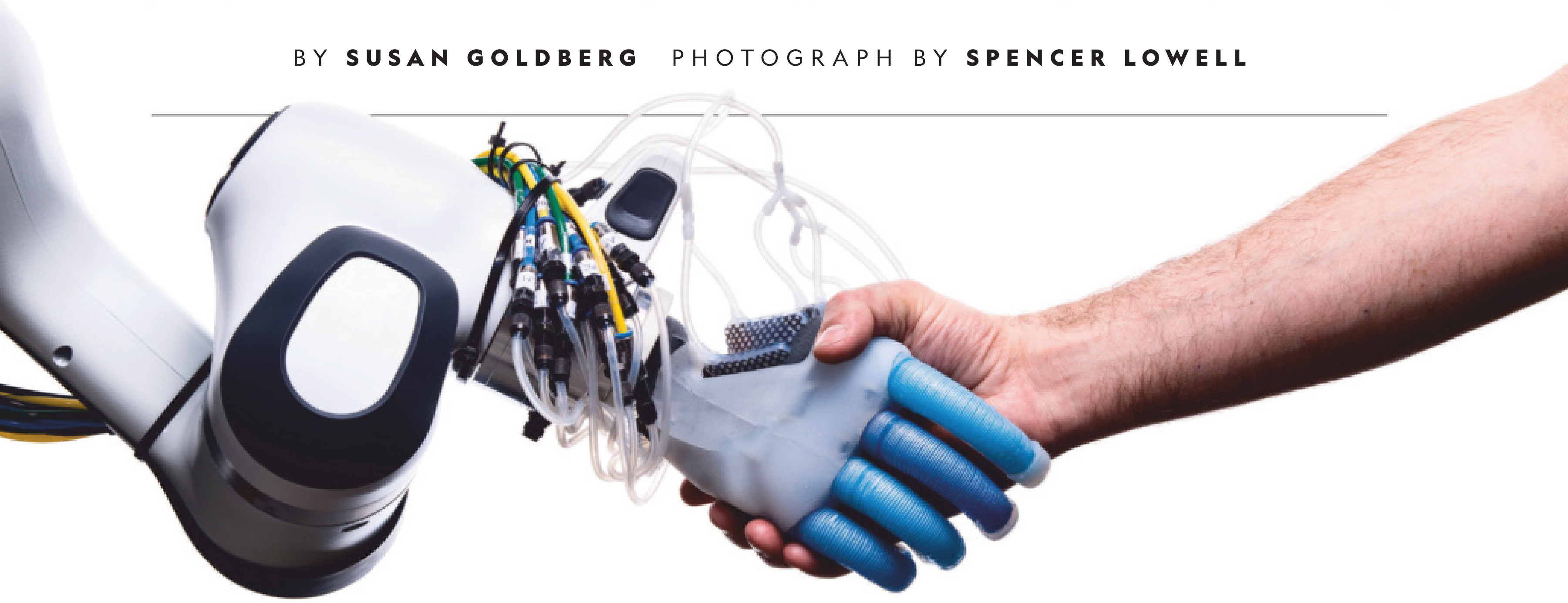
ROBOTICS

Meet the Machines in Our Future

BY **SUSAN GOLDBERG** PHOTOGRAPH BY **SPENCER LOWELL**



On this humanlike robotic hand, created at a Berlin university, the fingers are like "smart" air balloons. Inflated to precise specifications, the fingers can close around an object with a grip that's both dexterous and delicate. In the future, robots with such hands may handle merchandise in a warehouse or serve as fist-bumping greeters at amusement parks.

HUMANKIND HAS A complicated relationship with robots. On one hand, we appreciate how they can do dangerous, repetitive work so we don't have to. Robots don't need vacations or medical insurance. And in areas such as agriculture, where farmers can't find enough people to pick the produce, robots can shoulder (do they have shoulders?) some of those tasks. But polls show that the growing robotization of the planet makes us feel deeply uncomfortable—and threatened.

Pew Research Center surveys after 2017 found that more than 80 percent of Americans believed that by 2050, robots would do much of the work humans now do—and about 75 percent believed that would make economic inequality worse. Across lines of race, age, and education, people who said automation has hurt workers outpaced those who said it's helped workers by two to one.

Of course, these surveys were taken before COVID-19, when replacing people with robots began to look like a highly practical answer to social distancing, no masks required.

For this month's cover story, we sent David Berreby around the world to look at the present and future state of robots in society. He found a growing reliance on these intelligent devices.

"Robots now deliver food in Milton Keynes, England, tote supplies in a Dallas hospital, disinfect patients' rooms in China and Europe, and wander parks in Singapore, nagging pedestrians to maintain social distance," Berreby writes. He found robots digging holes to install wind turbines in Colorado, cutting lettuce in California, and even reciting religious texts in Japan.

"It's an inevitable fact that we are going to have machines, artificial creatures, that will be a part of our daily life," Carnegie Mellon University AI roboticist Manuela Veloso told Berreby. "When you start accepting robots around you, like a third species, along with pets and humans, you want to relate to them."

A third species? That's a new idea indeed. But we're not there yet. So far, Berreby reports, robots can't equal the human mind's ability to do a lot of different tasks, especially unexpected ones, and robots haven't yet mastered common sense—all skills required to be a magazine editor.

But give it a few years. Until then, let me personally thank you for reading *National Geographic*. ☐

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with Pizza Crusts & Sauce
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Natural Uncured Pepperoni & Natural Cheese made with nothing artificial.

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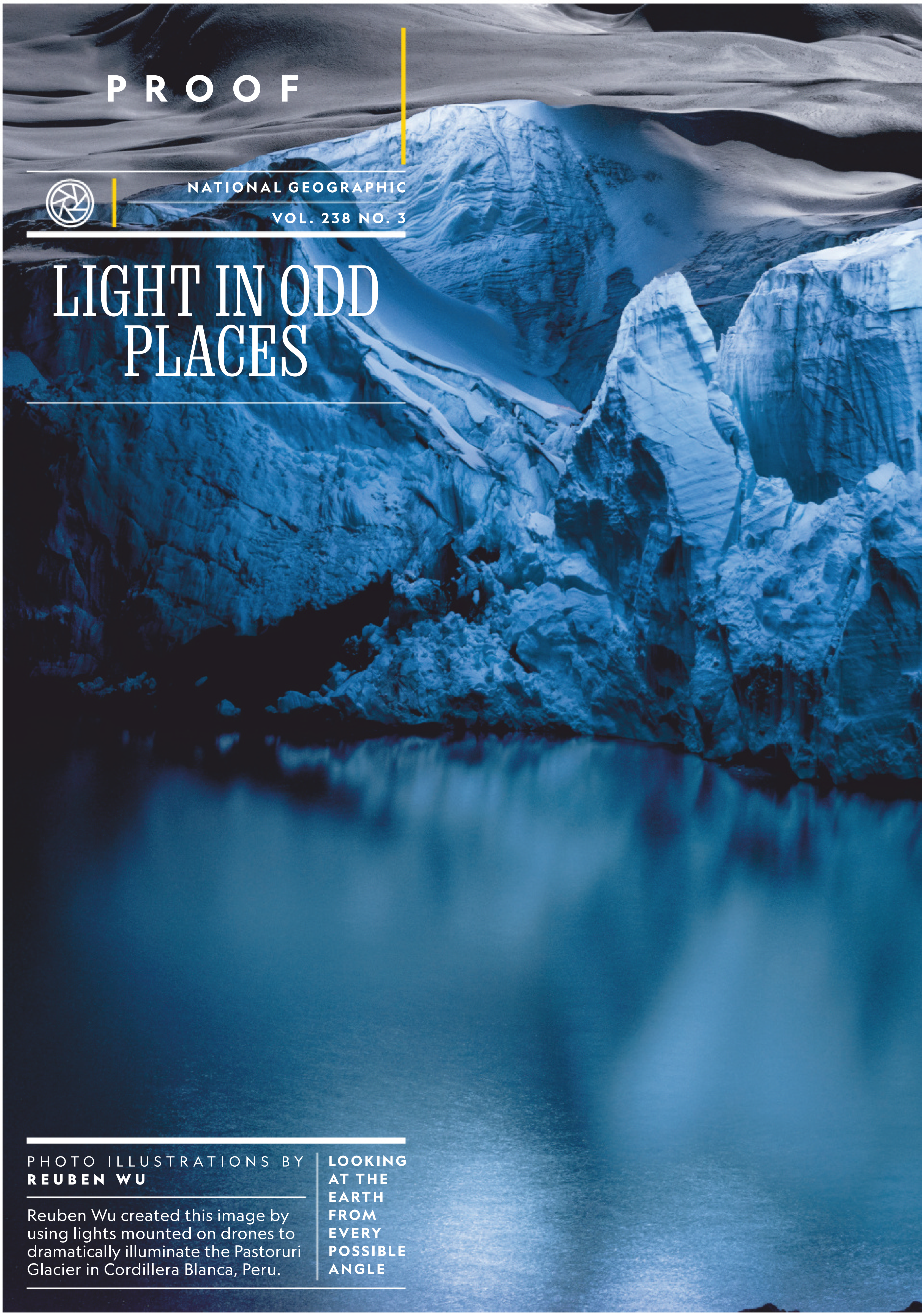


PROOF

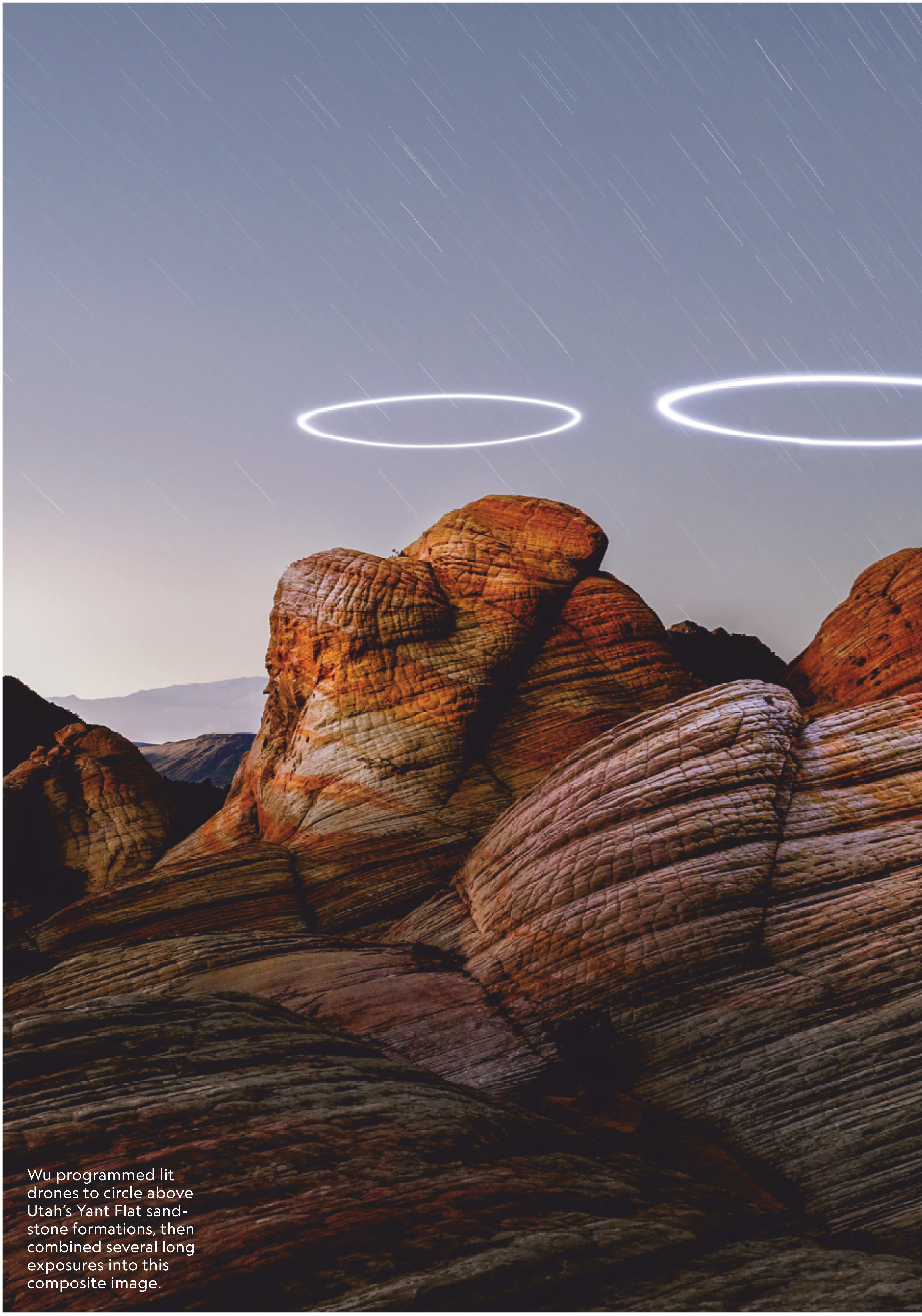
NATIONAL GEOGRAPHIC
VOL. 238 NO. 3

LIGHT IN ODD PLACES

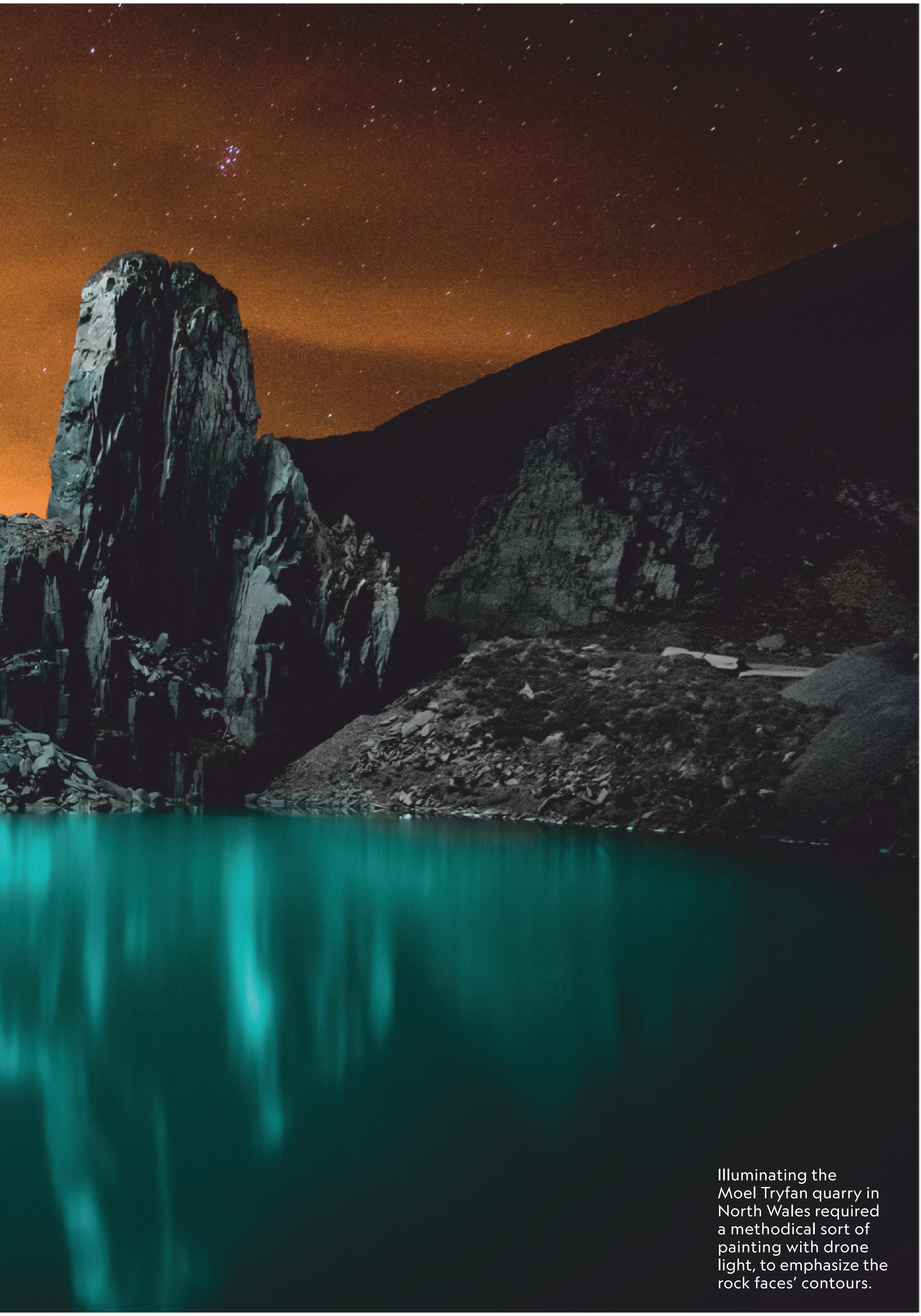
PHOTO ILLUSTRATIONS BY
REUBEN WU

Reuben Wu created this image by using lights mounted on drones to dramatically illuminate the Pastoruri Glacier in Cordillera Blanca, Peru.

LOOKING AT THE EARTH FROM EVERY POSSIBLE ANGLE



Wu programmed lit drones to circle above Utah's Yant Flat sandstone formations, then combined several long exposures into this composite image.



Illuminating the Moel Tryfan quarry in North Wales required a methodical sort of painting with drone light, to emphasize the rock faces' contours.

THE BACKSTORY

PUTTING ARTIFICIAL LIGHT IN A NATURAL ENVIRONMENT ADDS AN ILLUMINATING KIND OF AWE.

THE IMPRESSIVE LANDSCAPES on Earth can take a person's breath away. But for Reuben Wu, that wasn't enough. Wu—a photographer, visual artist, and music producer—felt that the planet's majestic mountains, glaciers, and beaches were missing something.

Specifically, unnatural lighting.

The idea was born from a mistake. One night near Death Valley, California, Wu set a camera to make a time-lapse series in the dark. A pickup truck drove by and washed out the scene with its harsh headlights.

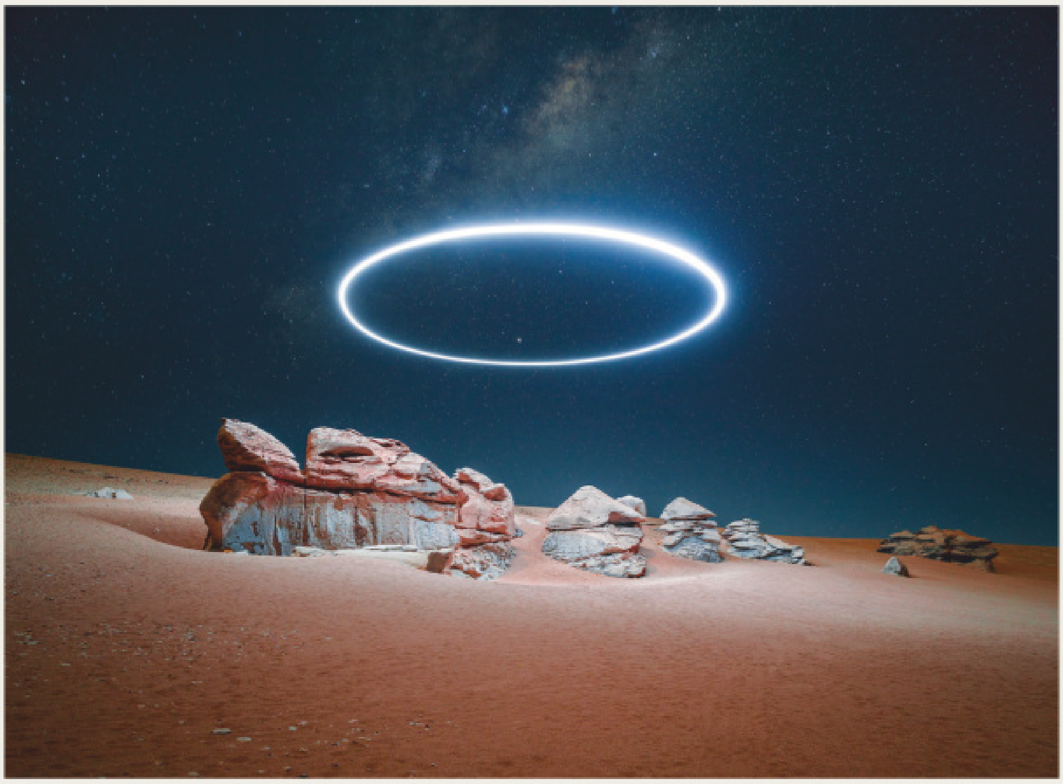
At first, says Wu, "I was really annoyed. But when I looked at the images, I was fascinated. Here was artificial lighting in a natural environment."

The juxtaposition launched his desire to try adding light to other scenes where it didn't belong: on lakes, in canyons, on tall rock pillars in the desert. He flew drones carrying lights in front of cameras, taking long exposures—as long as 30 seconds. Then he layered the images into composites and, in some images, retouched the final version to remove the drone but leave the light it cast.

What emerged were incongruous, otherworldly landscapes, each a visual puzzle daring the observer to figure out how such a scene came to be.

Wu photographs mostly in the United States, where he lives. But in the spirit of exploration, he says, any landscape on Earth is a candidate for such a portrait—any scene, anywhere, that can be captured in a way it doesn't usually appear.

Wu intends for the series to confound: Is it nature? Is it art? Disorientation, he says, opens the mind to another way of seeing. —DANIEL STONE



Wu cast a different sort of light on rock formations near Arbol de Piedra, Eduardo Avaroa Andean Fauna National Reserve of Sur Lípez Province, Bolivia.

CORONAVIRUS

IN THIS SECTION

The Laboratory Tools for Handling Deadly Virus

Flattening the Curve in the 1918 Flu Epidemic

A SPECIAL REPORT FROM NATIONAL GEOGRAPHIC

NATIONAL GEOGRAPHIC | **VOL. 238 NO. 3**

The Cost of Harming Nature

THE PANDEMIC PROVES IT: BY DAMAGING THE PLANET, WE HAVE SAPPED NATURE'S POWER TO PROTECT US FROM DISEASES.

BY **ENRIC SALA**

SINCE MY CHILDHOOD by the Mediterranean Sea, I've been enchanted by the diversity of life on our planet and eager to learn all I could about it. I've spent much of my career studying the ocean food web, where in the course of natural events the smallest of the small are consumed by larger and larger predators, often ending in us. But scientists know there is more to the story, and I've been humbled to see life on our planet brought to a standstill by a tiny virus.

From a Wuhan, China, "wet market" where freshly butchered meat and live wild animals are sold for food and medicine, the virus likely was transmitted in late 2019 via wildlife to humans. And in a matter of months, COVID-19 has felled hundreds of thousands of *Homo sapiens,* Earth's preeminent predator.

Writing about this for my new book, I was deeply saddened: The virus has struck people I knew, in Europe and around the world. But this pandemic is a powerful argument for something I believe

Conservation is not just a luxury

In ancient times smaller human groups and restricted mobility probably kept diseases local. But over the course of history, humanity has made it very easy for viruses to become evolutionarily successful. We gather in great densities in urban areas and move around the globe like no other species ever has before. We've turned wild habitats into cities, farmland, and shopping malls, crowding in on the species with which we share this planet. We've created the perfect conditions for a modern plague.

COVID-19 is yet another reminder that conservation is not just a luxury for rich countries or a romantic ideal. Our very survival depends on our being better members of the biosphere, our larger community. **—ES** unequivocally: that biodiversity is necessary for human health, and ultimately, human survival.

PEOPLE HAVE BEEN ACQUIRING harmful viruses and bacteria from contact with animals in the wild for millennia. As humans relentlessly encroach upon wild habitats and compete with animals for water, food, and territory, there's bound to be more physical contact, yielding more conflict—and more contagion.

A 2020 study explored the link between the abundance of species that carry such zoonotic viruses and the likelihood of spillover to humans. Researchers combed the scientific literature, obtained data on 142 zoonotic viruses, and found that rodents, primates, and bats carried more of these viruses than other species. The researchers also found that the risk of virus transmission to humans was highest from animals that are more abundant, because they have adapted to human-dominated environments.

What about risks from the creatures in the ocean, which is more than 70 percent of the planet? Does our exploitation of ocean life also threaten human health? I discovered the answer during our exploration of some of the most remote islands in the central Pacific.

In 2005 I organized my first research expedition to Kingman Reef and neighboring islands. Kingman is the northernmost of the Line Islands, 11 coral islands and atolls that stretch 1,460 miles across the Equator, 1,070 miles southwest of Honolulu. Visiting four of the islands north of the Equator provided the perfect natural experiment to compare different levels of human impact on coral reefs.

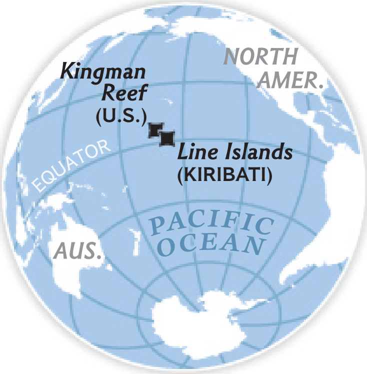
Kingman was uninhabited. The next island to the south, Palmyra, had 20 people manning a research station and wildlife refuge. Farther south were Teraina (with 900 people at the time), Tabuaeran (2,500 people), and Kiritimati (5,100 people), which are part of the Republic of Kiribati. These four islands were close enough to share oceanographic and climate conditions, flora, and fauna. The variable that changed across the islands was the number of humans present.

Our team of scientists set out to assess the diversity and abundance of everything—viruses, bacteria, algae, invertebrates, and fish—and to measure how the coral reef ecosystem changes along a gradient of human disturbance. In five weeks of dives, we counted and estimated the abundance and biomass of everything we could. What we found was clear: When people, even just a few hundred, start fishing, they trim the food web from the top. And as their number increases from none to just a few thousand, the coral reef shifts from one with lots of sharks and corals to one without sharks but with lots of small fish and seaweed.

We made another discovery that I had not expected about the smallest creatures on the reef, though.

I WILL NEVER REGRET inviting my dear friend Forest Rohwer to join the expedition. Forest is a brilliant viral ecologist at San Diego State University and among the first to use genomic technology to study

A wave breaks over the reef crest at Kingman Reef, part of the U.S. Pacific Remote Islands Marine National Monument.



NGM MAPS. PHOTO: ENRIC SALA

viruses and bacteria in the ocean. That year in the Line Islands, Forest and his small team collected water samples to measure microbe abundance relative to human presence. They found 10 times as much bacteria in the water in Kiritimati than in Kingman.

Not only did the microbial numbers increase with greater numbers of people; what the bacteria did also changed dramatically. At Kingman we found crystal clear waters, where half the microbes were very small bacteria like *Prochlorococcus,* which simply photosynthesize for a living. By contrast, at Kiritimati we found murky waters where about a third of the bacteria were pathogens, including several types of *Staphylococcus, Vibrio,* and *Escherichia*.

Especially worrying was *Vibrio,* which can cause diseases in corals, contributing to the shift from coral-dominated to seaweed-dominated reefs, which in turn enhance microbial blooms. *Vibrio* can also cause fatal diseases in humans, such as cholera, gastroenteritis, wound infections, and septicemia. Forest calls this ecosystem shift—from mature, stable, and full of large animals to immature and dominated by small creatures—the "microbialization" of coral reefs.

In April and May 2009 we conducted the first National Geographic Pristine Seas expedition to five of the Line Islands south of the Equator, all uninhabited. There we found what we had found at Kingman: clean water and extremely high fish biomass, including many sharks, and a reef dominated by living coral. In the lagoon of Millennium Atoll, we marveled at the abundance of giant clams—something we had also observed in the lagoon at Kingman.

Giant clams filter water through their bodies and capture microorganisms from it for food, and we wondered how much they helped to keep the water that clean. Forest collected water from the lagoon and filled experimental aquariums on board our ship: some with a living giant clam in them, some with an empty clamshell, and some with nothing but water. Then he measured the abundance of bacteria and viruses over time. The results were astonishing. The giant clams removed most bacteria and viruses from the seawater within 12 hours, while the water in the other aquariums became turbid and loaded with microbes. Forest then added *Vibrio* to each aquarium, from a culture he had brought with him on the expedition. (Who else travels with *Vibrio*?) As expected, the giant clams in the experimental aquariums significantly reduced *Vibrio,* which thrived in the control aquariums.

> IF WE DEGRADE HABITATS, ANIMALS BECOME STRESSED AND SHED MORE VIRUSES. ON THE OTHER HAND, HABITATS WITH DIVERSE SPECIES HARBOR LESS DISEASE.

It's another way nature controls viruses—filtering them out of the system—that we're only now recognizing. Giant clams have been harvested for meat and shells from most reefs in the Pacific and are almost gone in many places. People have unknowingly been removing natural filters—the N95 masks of the lagoon—that were protecting them against disease.

WE ARE ALL IN THIS together, all species on the planet. So what can we do? While the world has stepped up to help those in need during the COVID-19 outbreaks, we might also start thinking about how to prevent the next zoonotic pandemic.

We have seen, again and again, that even though we don't know what most of them do, all wild animals have important jobs that keep our biosphere running. If we've learned anything from our study of natural ecosystems as it applies to these recent diseases, it's that instead of exterminating wild animals to stop the passage of disease to people, we should do the opposite: We should safeguard the natural ecosystems that are their homes and, if needed, help set them back on their path to maturity through rewilding.

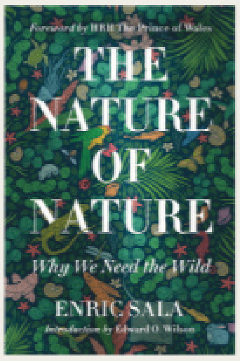
If we degrade habitats, animals become stressed and shed more viruses. On the other hand, habitats with diverse microbial, plant, and animal species harbor less disease. Biodiversity dilutes any viruses that emerge and provides a natural shield that absorbs the fallout from pathogens.

Clamping down on the illegal trade of wildlife, ending deforestation, protecting intact ecosystems, educating people about the risks of consuming wildlife, changing the way we produce food, phasing out fossil fuels, and transitioning to a circular economy: These are the things we can and must do.

Even if it's just for selfish reasons—for our own survival—now more than ever, we need the wild. A healthy natural world is our best antivirus. □

The essential wild

Renowned ecologist and oceanographer **Enric Sala** is an explorer-in-residence at the National Geographic Society. This essay is drawn from his book *The Nature of Nature: Why We Need the Wild,* with a foreword by the Prince of Wales and an introduction by biologist E.O. Wilson.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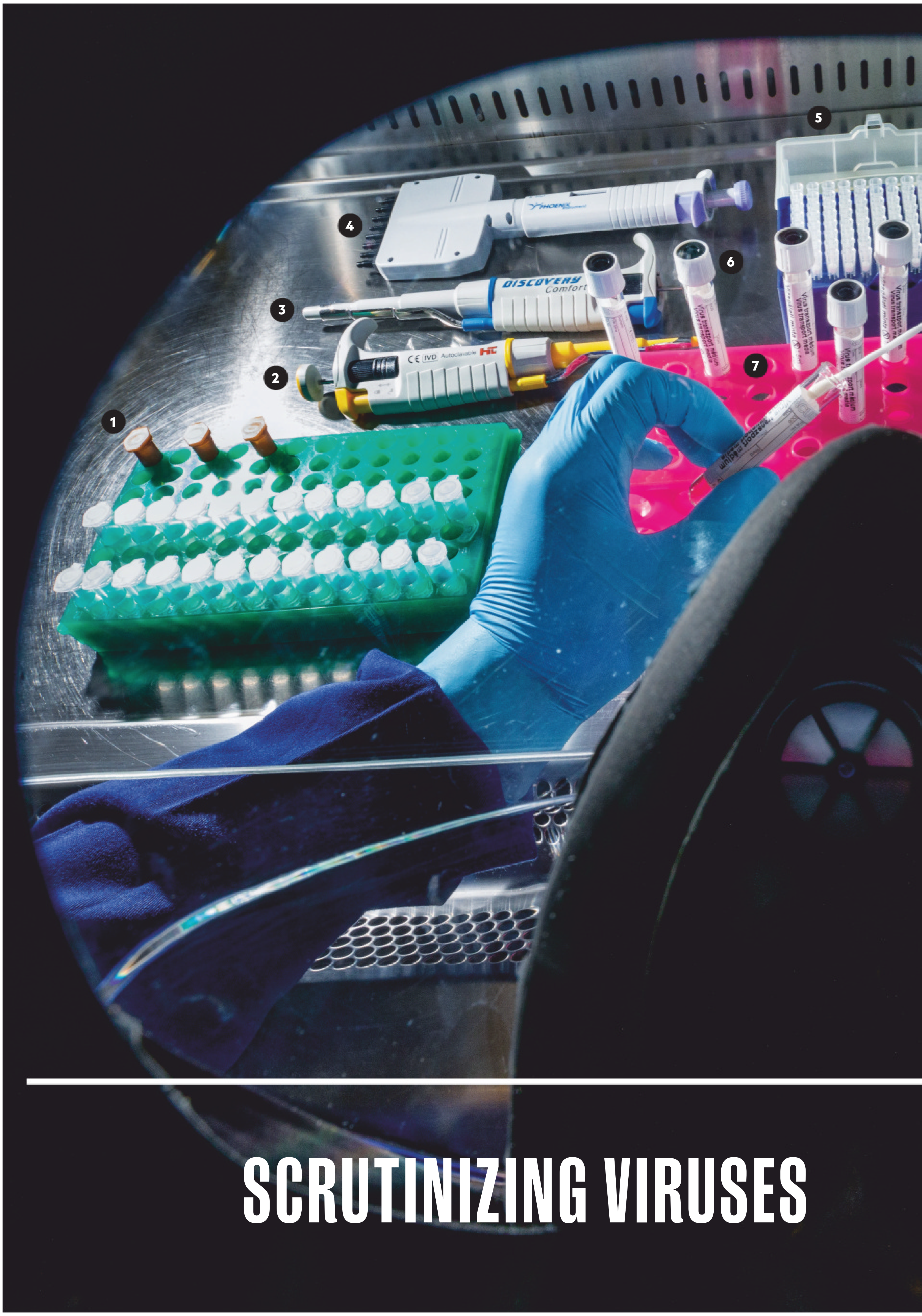
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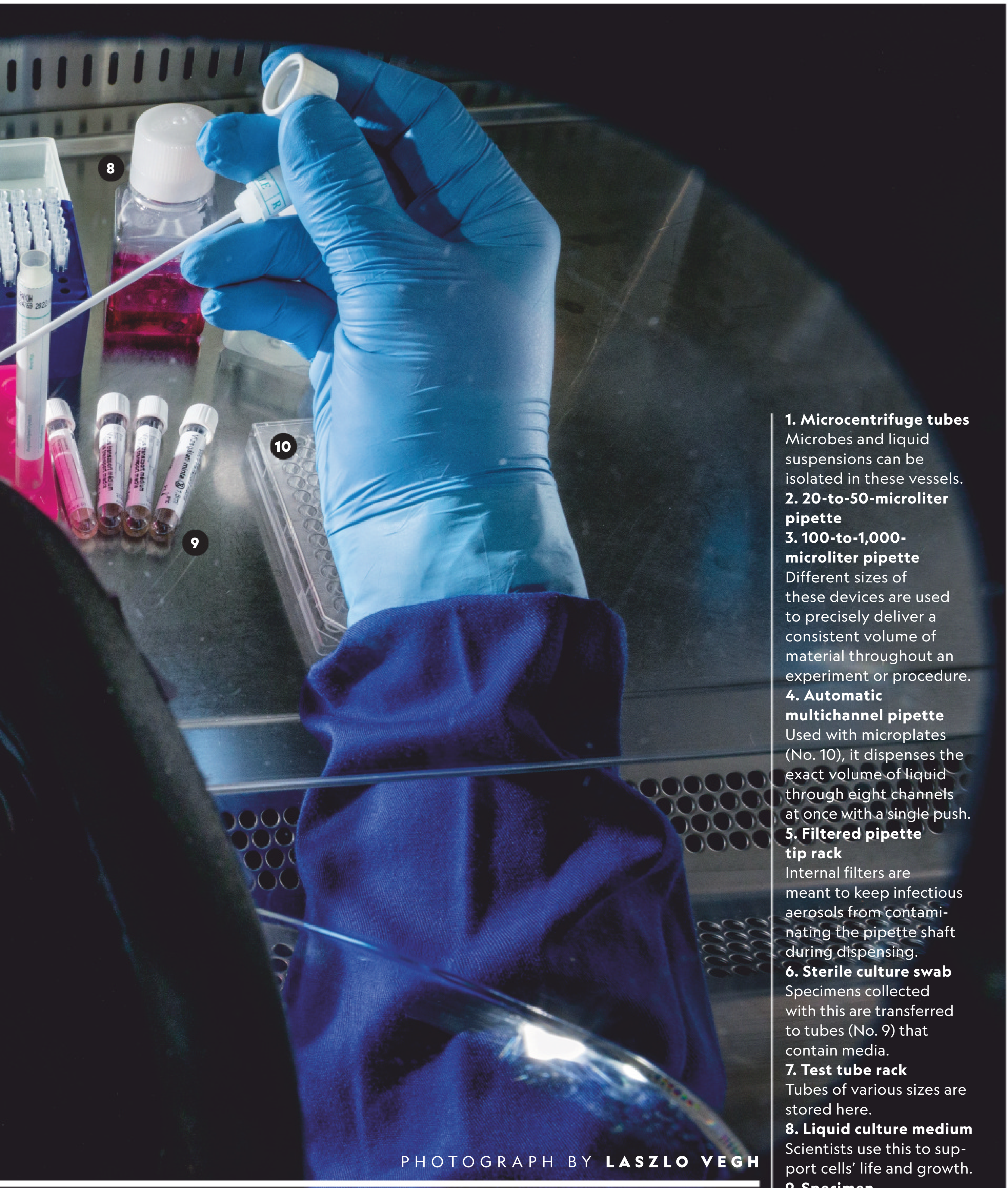
SCRUTINIZING VIRUSES



PHOTOGRAPH BY **LASZLO VEGH**

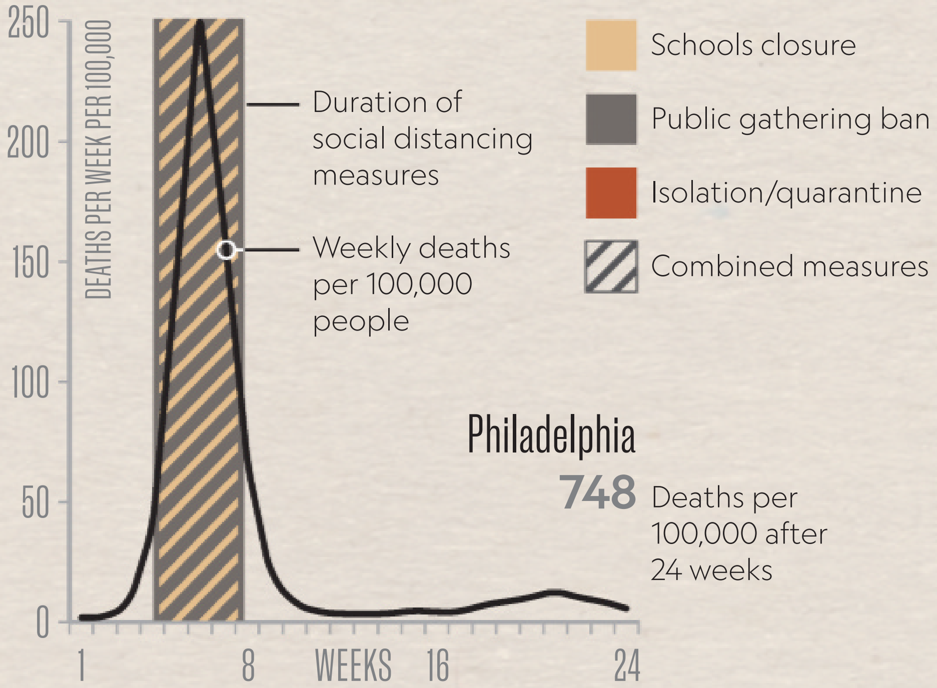
LABORATORIES LIKE THIS "high containment" facility are used to safely handle infectious agents. Whether detecting pathogens and diagnosing diseases or unraveling the molecular structure of microbes, scientists use specialized tools with great care. This lab, at the Szentágothai Research Center at Hungary's University of Pécs, is rated at a high biosafety level, meaning that transmission of microbes handled here can cause serious or deadly disease. This work space is photographed through a technician's face shield and past its respirator mask valve. —TAMAS VITRAY, JR.

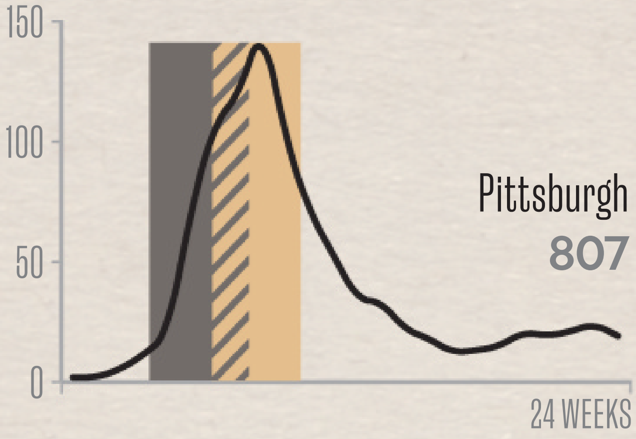
1. Microcentrifuge tubes
Microbes and liquid suspensions can be isolated in these vessels.
2. 20-to-50-microliter pipette
3. 100-to-1,000-microliter pipette
Different sizes of these devices are used to precisely deliver a consistent volume of material throughout an experiment or procedure.
4. Automatic multichannel pipette
Used with microplates (No. 10), it dispenses the exact volume of liquid through eight channels at once with a single push.
5. Filtered pipette tip rack
Internal filters are meant to keep infectious aerosols from contaminating the pipette shaft during dispensing.
6. Sterile culture swab
Specimens collected with this are transferred to tubes (No. 9) that contain media.
7. Test tube rack
Tubes of various sizes are stored here.
8. Liquid culture medium
Scientists use this to support cells' life and growth.
9. Specimen collection tubes
These are designed to protect the integrity of samples and eliminate the risk of spillage.
10. 96-well microplate
The wells function like small test tubes for titration—that is, measuring the concentration of virus or antibodies in a sample.

FLATTENING THE CURVE

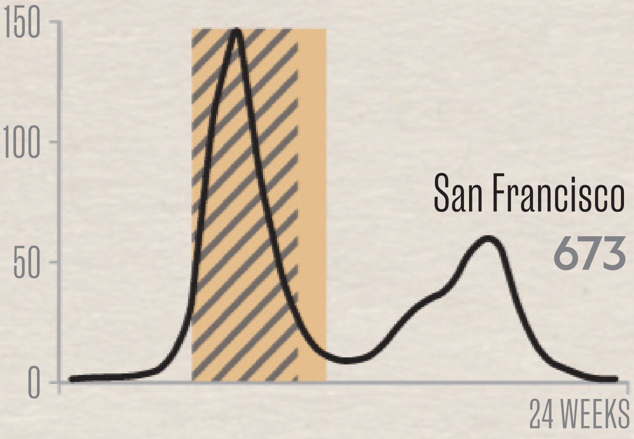
Cities in the United States used a wide range of interventions to try to contain the 1918 pandemic—from closing schools and banning public gatherings to enforcing isolation and quarantine. Each city shown here adopted at least one measure.

Philadelphia waited eight days after the city's death rate began to take off before banning gatherings and closing schools—and suffered the highest peak weekly death rate.

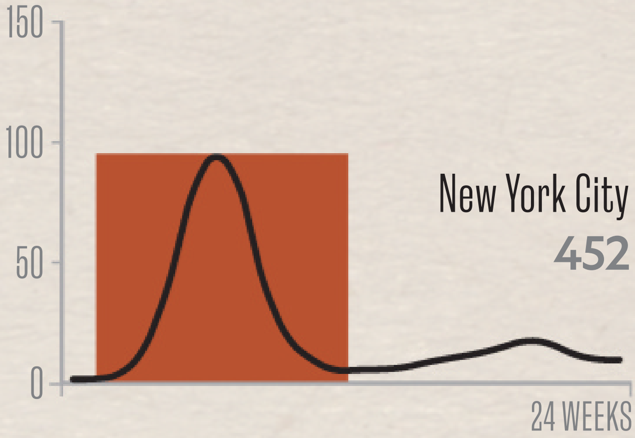




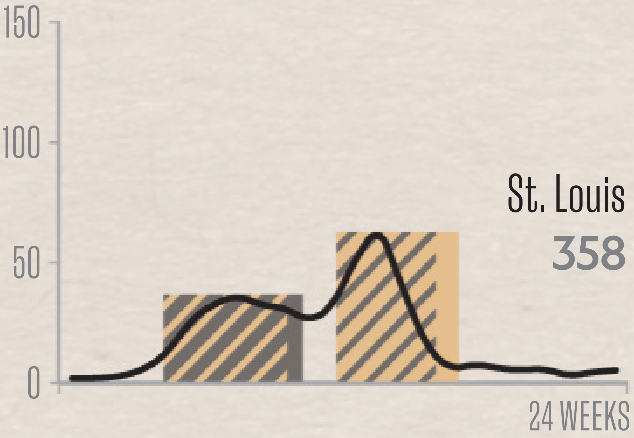
Pittsburgh had the highest mortality rate over the 24-week period. Not only did it delay measures by seven days, it also staggered instead of combining them.



San Francisco experienced a second wave of deaths after relaxing the social distancing measures that had initially curbed the disease.



New York City began quarantine measures early—11 days before the death rate spiked. The metropolis had the lowest overall death rate on the eastern seaboard.



St. Louis had strong distancing measures and a low total death rate. The city successfully delayed its peak in deaths, but faced a sharp increase when restrictions were relaxed.

IN 1918

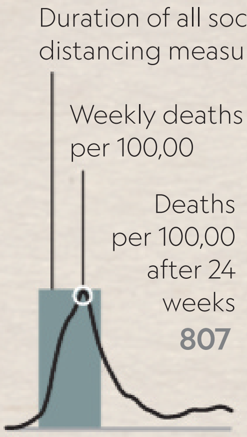
THE 1918 INFLUENZA PANDEMIC—ALSO KNOWN AS THE SPANISH FLU— wreaked havoc into 1920 and earned the dubious honor of being the deadliest pandemic in recorded history. In 2020, as many parts of the world grind to a halt in response to the coronavirus, experts have turned to this century-old outbreak for clues. The efforts made back then to stem the flu's spread in cities across America, and the outcomes—some grim, some inspiring—continue to offer lessons for today.

BY **RILEY D. CHAMPINE** AND **DIANA MARQUES**

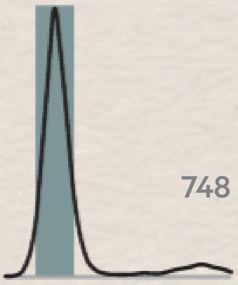
The time of implementation and duration of social distancing measures proved to be significant factors in a city's mortality rate.

Later and spikier

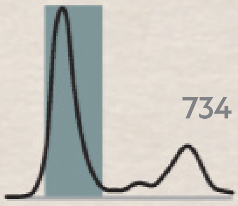
Cities that ordered measures later and for shorter periods tended to have spikes in deaths and higher overall death rates.



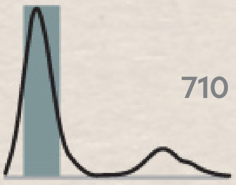
Pittsburgh



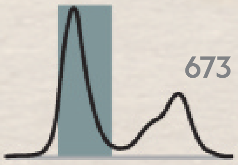
Philadelphia



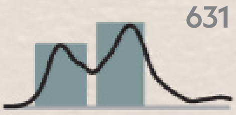
New Orleans



Boston



San Francisco



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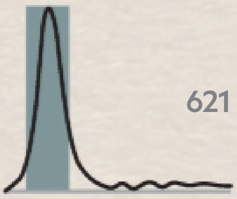

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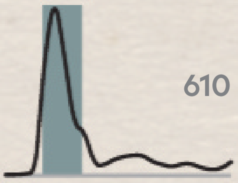

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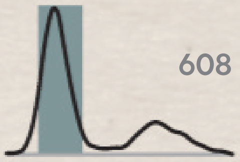

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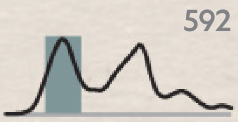

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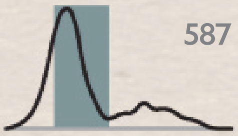

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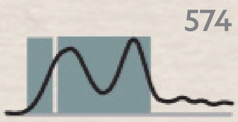

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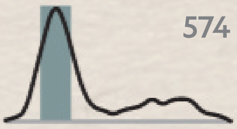

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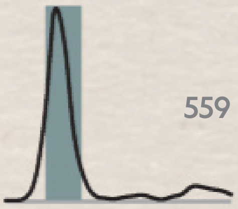

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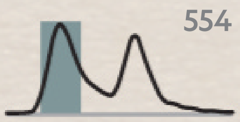
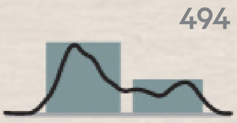


Omaha, Nebr.

Sooner and flatter

Cities that ordered measures sooner and for longer periods usually slowed infections and lowered overall death rates.



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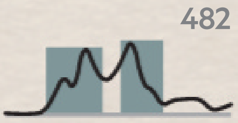

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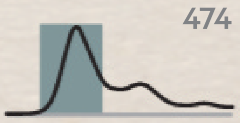

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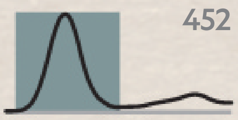
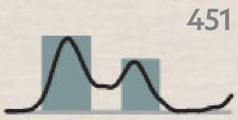


New York City



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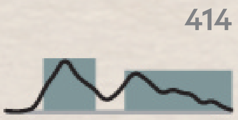

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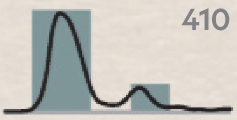

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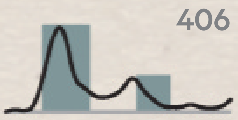

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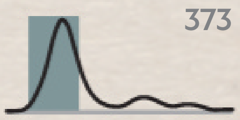
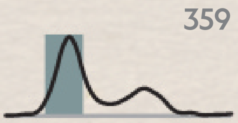


Chicago



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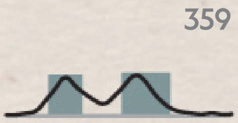

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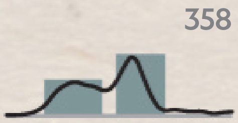
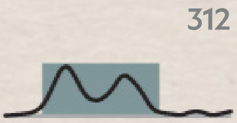
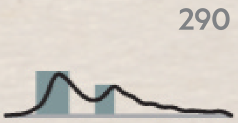


St. Louis



Columbus, Ohio



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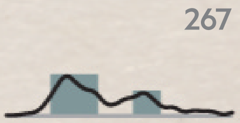

Minneapolis

SOURCES: HOWARD MARKEL AND J. ALEXANDER NAVARRO, CENTER FOR THE HISTORY OF MEDICINE, UNIVERSITY OF MICHIGAN

EXPLORE

IN THIS SECTION
Fossil Footprints
Flamingo Pals
How Eels Shock
Odd Turtle Traits

ILLUMINATING THE MYSTERIES—AND WONDERS—ALL AROUND US EVERY DAY
NATIONAL GEOGRAPHIC | VOL. 238 NO. 3

CAPTURED

A BRAIN CIRCUITRY MAP WORTH BUZZING ABOUT

This bundle of about 600 fruit fly neurons, colored for contrast, allows a fly to integrate and act on information that its senses gather. Scientists from the Janelia Research Campus and Google have so far mapped about a third of the fly brain, 25,000 nerve cells that form some 20 million connections. The ultimate goal: To map the whole brain and key nerves, to learn more about how the organ's areas are linked.

– THERESA MACHEMER

IMAGE: HOWARD HUGHES MEDICAL INSTITUTE'S JANELIA RESEARCH CAMPUS; GOOGLE; AND WELLCOME TRUST

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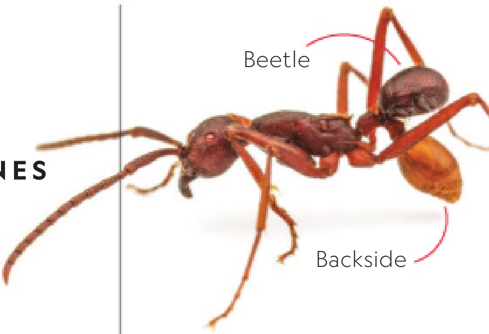
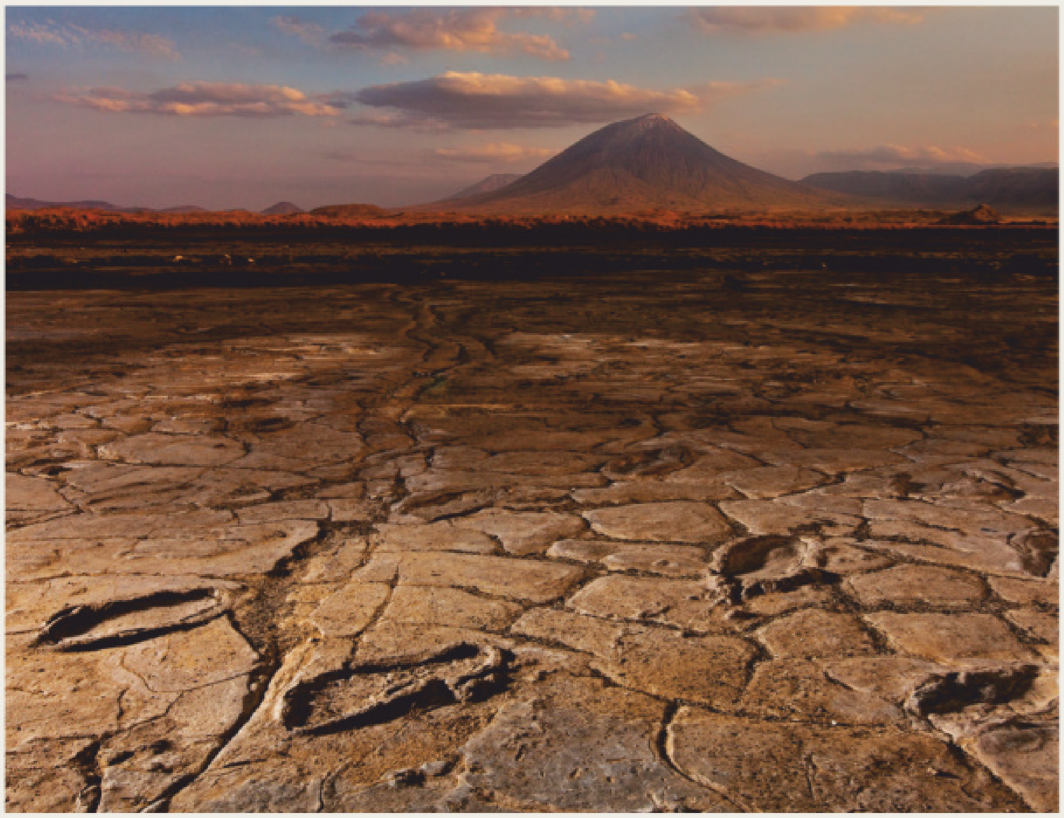
DISPATCHES
FROM THE FRONT LINES
OF SCIENCE
AND INNOVATION



This army ant bears a beetle behind

When colonies of hundreds of thousands of army ants go on the march, with them go symbionts that sponge off the army's resources—and members. One symbiont found in Costa Rica was hiding in plain sight: a beetle that clamps its mandibles around the ant's middle and rides along, looking like a double-vision version of the ant's backside. —PATRICIA EDMONDS



PALEOANTHROPOLOGY

WALKING BACK IN TIME, IN A VOLCANO'S SHADOW

A TANZANIAN VILLAGER HAS DISCOVERED A TREASURE TROVE OF ANCIENT FOOTPRINTS.

NINE MILES NORTH of the volcano called Ol Doinyo Lengai, which means "mountain of God," researchers funded by the National Geographic Society have cataloged a rare find: more than 400 fossil footprints (above) laid down by humans who walked and jogged across mudflats 10,000 to 19,000 years ago. Discovered along the shore of Tanzania's Lake Natron by local villager Kongo Sakkae, the Engare Sero site lets scientists "really start to see social behavioral patterns in our *Homo sapiens* ancestors," says team leader Cynthia Liutkus-Pierce, a geologist at Appalachian State University. One set of tracks reveals 17 people walking toward the southwest, 14 of whom were probably adult women. That suggests a female-led foraging party, a division of labor used by some modern hunter-gatherers. To save Engare Sero's trackways from erosion, researchers have 3D-scanned them and are partnering with local officials to build a protective enclosure and workstation. In the meantime, Sakkae walks to Engare Sero from his village every day at sunrise, keeping a watchful eye on the footprints he found. —MICHAEL GRESHKO

ANIMAL BEHAVIOR

Flamingos make friends

The avian world's pink-feathered icons form long-lasting, loyal friendships, scientists recently discovered. The flamingo bonds vary, from mated couples that build nests and raise chicks each year to same-sex friends or groups of three to six close buddies. The relationships, characterized by standing close together, may last decades. Like humans, flamingos befriend those they get along with and avoid those that cause squabbles. —VIRGINIA MORELL

PHOTOS (FROM TOP): DANIEL KRONAUER; ROBERT CLARK; ROY TOFT

FROM SEA TO SHINING SEA

AMERICA THE BEAUTIFUL

NATIONAL GEOGRAPHIC

A STORY IN PHOTOGRAPHS

CELEBRATING AMERICA IN ALL ITS GLORY, this inspiring collection of photography includes more than 250 National Geographic images from across the United States. From New York's Empire State Building and Washington's Mount Rainier to the coral reefs of American Samoa and the sprawling badlands of North Dakota, this majestic book features both the iconic and hidden gems of our beautiful country. This is a treasury for every American coffee table.

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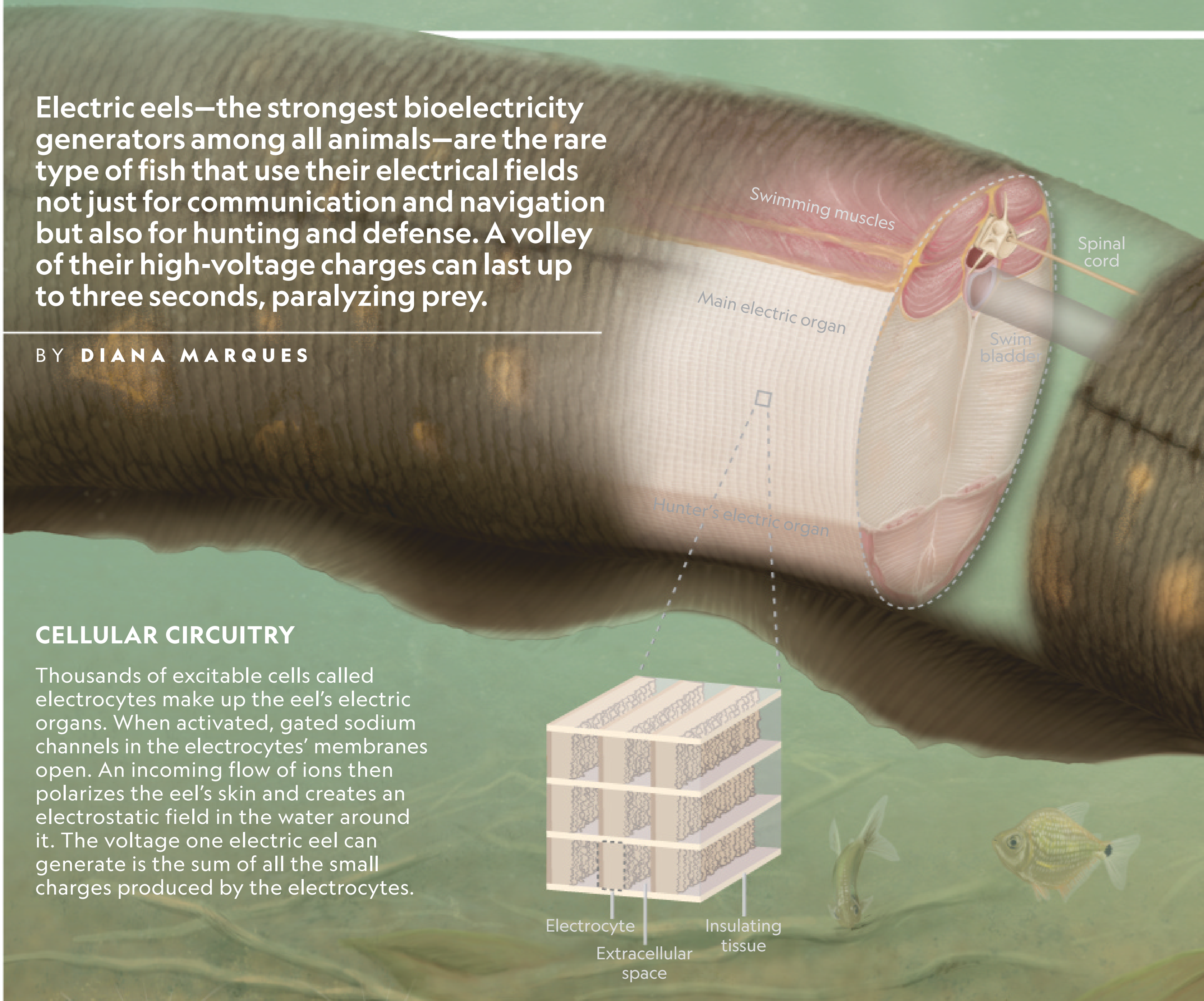
SHOCKING BEHAVIOR

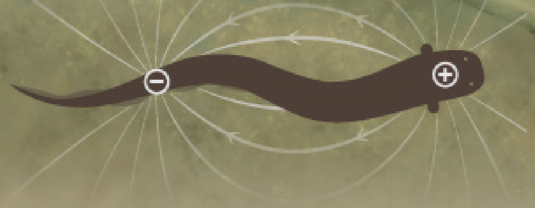
Electric eels—the strongest bioelectricity generators among all animals—are the rare type of fish that use their electrical fields not just for communication and navigation but also for hunting and defense. A volley of their high-voltage charges can last up to three seconds, paralyzing prey.

BY **DIANA MARQUES**


Swimming muscles
Spinal cord
Main electric organ
Swim bladder
Hunter's electric organ
Electrocyte
Extracellular space
Insulating tissue

CELLULAR CIRCUITRY

Thousands of excitable cells called electrocytes make up the eel's electric organs. When activated, gated sodium channels in the electrocytes' membranes open. An incoming flow of ions then polarizes the eel's skin and creates an electrostatic field in the water around it. The voltage one electric eel can generate is the sum of all the small charges produced by the electrocytes.



Current flows from head to tail. Scientists are still unsure why eels take on a wavy shape when discharging high voltages.

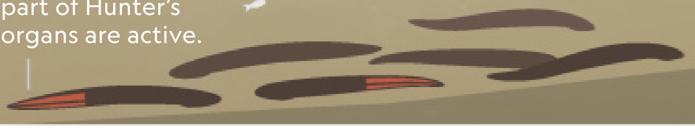
TOP CHARGERS

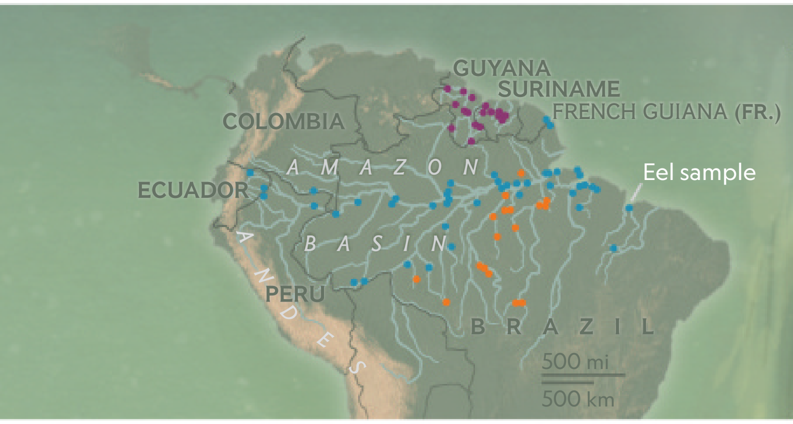
Once believed to be solitary animals, Volta's eels have recently been observed living and hunting in groups of up to a hundred individuals. Their collective hunting strategy and high discharge helps them overwhelm active shoals of small prey.

1

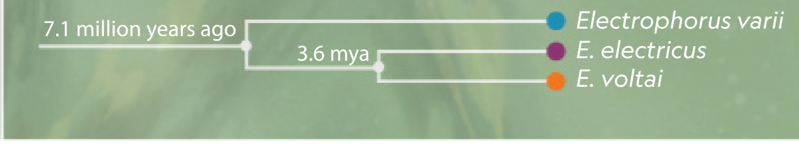
Resting as a group

Eels rest at the bottom of lakes most of the day and night. They communicate through low-voltage discharges emitted by some of their electric organs.

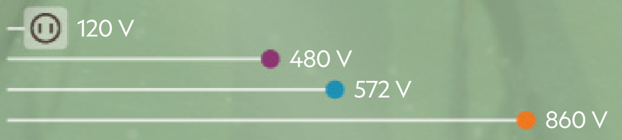

Sachs's and posterior part of Hunter's organs are active.


GUYANA
SURINAME
FRENCH GUIANA (FR.)
COLOMBIA
ECUADOR
AMAZON
BASIN
PERU
ANDES
BRAZIL
Eel sample
500 mi
500 km

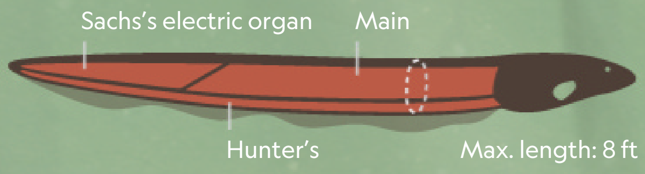
All three electric eel species are found in tropical South America. *Electrophorus varii* evolved in lowland waters that were murky, slow flowing, and mineral-rich. *E. electricus* and *E. voltai* adapted to highland rivers where water is clear and mineral-deprived. Some experts believe that *E. electricus* and *E. voltai* split as species when the Amazon changed to its modern course.

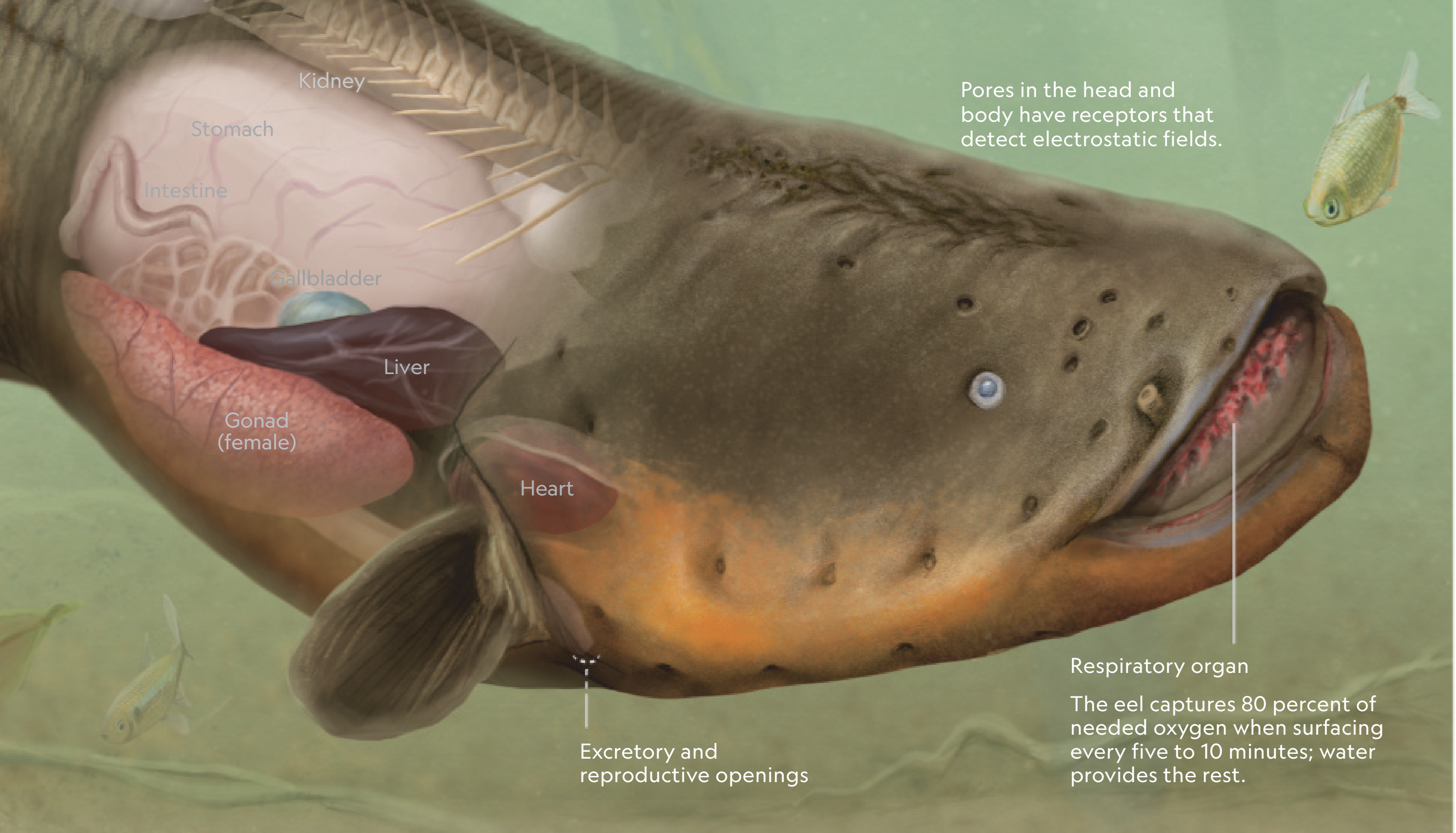

7.1 million years ago
3.6 mya
Electrophorus varii
E. electricus
E. voltai

When it comes to electricity generation, Volta's eels *(E. voltai)*, depicted here, reign supreme. Their charge can be seven times stronger than a wall socket's.



Three electric organs take up 80 percent of the body.


Sachs's electric organ
Main
Hunter's
Max. length: 8 ft


Kidney
Stomach
Intestine
Gallbladder
Liver
Gonad (female)
Heart

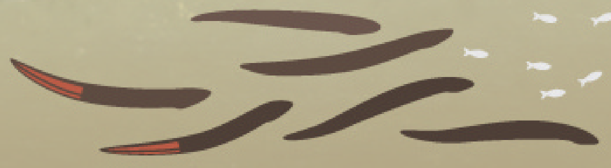
All vital organs are confined to this small area behind the head.

Pores in the head and body have receptors that detect electrostatic fields.

Respiratory organ

The eel captures 80 percent of needed oxygen when surfacing every five to 10 minutes; water provides the rest.

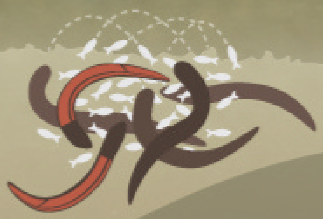
Excretory and reproductive openings



2

Moving at dawn and dusk

Twice a day, when light intensity is low, eels start swimming near the surface. They migrate to a shallow hunting area.



All electric organs are engaged.

3

The electric feast

Eels herd thousands of small fish into a prey ball and take turns zapping them. Stunned fish fly up, fall back into the water, and get swallowed alive.

SOURCES: DAVID SANTANA, SMITHSONIAN INSTITUTION; DOUGLAS BASTOS, INPA; PHILIP STODDARD, FLORIDA INTERNATIONAL UNIVERSITY

INNOVATOR

ERIKA CUÉLLAR SOTO

BY **ANNIE ROTH** PHOTOGRAPH BY **MARK THIESSEN**

She helps Indigenous people protect the 'magic' of their lands.

When Bolivian conservation biologist Erika Cuéllar Soto saw the sun rise over the Gran Chaco for the first time, in 1997, she knew she was somewhere special. "The Gran Chaco is magic," she says. "I woke up and walked outside my tent, and tracks were everywhere." Wildlife abounds in the Gran Chaco, a lowland forest spanning the borders of Bolivia, Paraguay, Argentina, and Brazil. The semiarid, sparsely populated region has long been a refuge for jaguars, armadillos, giant anteaters, and guanacos, the dust-colored cousins of the llama. But in the past few decades, large swaths of its woodlands have been destroyed to make way for crops, ranches, and natural gas wells, and native species are struggling to maintain their foothold.

To preserve the Gran Chaco, Cuéllar has recruited Indigenous residents to be "parabiologists." They're like paramedics, she says, but for ecosystems. Cuéllar's training program helps Gran Chaco locals develop skills they can use as professional conservation biologists. "For me, there is no other way to achieve long-term conservation," she says. While sustainably earning a living, the parabiologists benefit their communities by managing fires and controlled burns, monitoring biodiversity, creating a reserve to protect guanacos—and teaching what they know.

"We are losing the knowledge of people that are really connected with nature," Cuéllar says. "You can't get that knowledge from the university."

Can a tiny bee save a giant elephant?

In the heart of Mozambique, at the edge of the Great African Rift Valley, you'll find the Gorongosa National Park.

A vast expanse of rainforest, grasslands, rivers, and some of the most amazing wildlife on Earth.

If you could go back in time a few years, you'd see many elephants roaming around Gorongosa. Back in 1972, there were 2,500 of them.

Then the Mozambican civil war struck

The Fifteen Years, Four Months, and Four Days War.

The elephants suffered terribly, hunted for their ivory so people could sell it to buy arms and supplies. By the end of the war, fewer than 200 elephants remained.

Traumatized, and with notoriously long memories, these elephant survivors don't trust people very much. With about 170,000 people living in and around Gorongosa, that can be a problem.

You try stopping a hungry elephant.

Most people in Gorongosa eat what they can grow on the ground, so if something goes wrong with their crops, they don't eat.

And things do go wrong. An infestation. A storm. A drought.

Or a group of hungry elephants with PTSD, looking for potatoes at night. Hungry elephants weary of people encounter hungry people weary of elephants. The people push, the elephants push back. Both sides get hurt, sometimes badly.

To the rescue: a young woman, a great idea, and... bees.

Enter young Mozambican ecologist Dominique Gonçalves.

She works at the Gorongosa National Park, managing the Elephant Ecology Project. She is also a National Geographic Fellow and Explorer, and she knows elephants very well. She even knows about a little phobia of theirs.

It turns out elephants are petrified of bees.

She strung a network of ropes along the boundaries of the crops. And hanging from the ropes... beehives. Elephants looking for food rattle the ropes, which really riles the bees. The sight and sound of the swarming bees makes the elephants flee before anyone gets hurt.

Now the villages are protected, the crops don't get ruined, and people don't have to resort to hurting the elephants to safeguard their food supply.

And there's an extra benefit: the locals now have honey to eat and sell.

We're more creative together.

A genially simple idea, at the cost of a few occasionally annoyed bees. That's what happens when the power of creativity meets a dedicated person's love for the planet.

We at the LEGO Group love stories like these. We want to keep reading them, and we want to keep helping to make them happen.

We know that creativity is an incredible skill, and the 21st century needs as much of it as it can get. We also know that building with LEGO® bricks helps kids begin to think creatively about the world, and we're always on the lookout for new ways to spark their imagination.

That's why LEGO® City and LEGO® Friends are now proud contributors to the National Geographic Society Explorer Grants. So we can help inspire the world explorers and creative problem-solvers of tomorrow, starting right now.

After all, if a little bee can make such a big difference, just imagine what a child with a big idea might achieve some day.

Creative ideas make the world a better place.

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The Celebrity at the Zoo

ALMOST EVERYBODY LOVES PANDAS. AFTER A YEAR DOCUMENTING A NEWBORN CUB, A PHOTOGRAPHER REMEMBERS WHEN SHE DID TOO.

STORY AND PHOTOGRAPHS
BY **REBECCA HALE**

IN ALMOST EVERY PHOTO from our 1986 family vacation to Washington, D.C., I am showing off the souvenir I picked out from the gift shop at the Smithsonian's National Zoo—a white, oversize, cotton sweatshirt with puff-paint pandas dancing on the front. I was nine years old, and pandas were cool. Not even midsummer heat could deter me from keeping that sweatshirt on throughout the trip.

I remember very little from the vacation, aside from the thrill of being at the zoo and seeing the giant pandas, Ling-Ling and Hsing-Hsing—star attractions on the tourist circuit. The following year Ling-Ling gave birth to twin cubs. The babies didn't survive, but I don't remember learning that as a kid.

Nearly 30 years later I found myself in the midst of a pool of photojournalists and video crews packed into the panda enclosure. A small cub named Bei Bei was being presented to the world, and I was covering it for *National Geographic*. The closest I'd come to photographing a subject that generated this level of frenzied enthusiasm was when Angelina Jolie visited the National Geographic Society headquarters for an event.

I confess that my childhood love of pandas hadn't lasted. I lived in D.C. by then. The pandas were just another item to mark off the tourist checklist, and photographing a new cub was part of my job. But I also had children, and, as most parents in the Washington area do, I'd take them regularly to the National Zoo.

I would join the throngs of residents and visitors pushing strollers up the never ending hill that winds through the grounds. By the time we reached the panda enclosure, my kids would inevitably be hot and thirsty, and sometimes crying. I would struggle to point out to my four-year-old just where to look, over the crowds also eager to catch a glimpse of the iconic black-and-white bears. Our visits left me completely drained. Though I was proud of the zoo in my adopted city, I found myself suggesting that we save future trips for visiting grandparents.

But in 2015, Bei Bei was born to Mei Xiang, and panda frenzy took over Washington. My editor asked me to document the cub's debut. As I'm a studio photographer at *National Geographic,* it isn't unusual for me to cover subjects in our urban backyard, but I am by no means a wildlife photographer. I sometimes joke that I'm the photographer equivalent of a Swiss army knife—shooting everything from portraits to artifacts. Pandas had never been on my list.

After the photographs of Bei Bei were published, my editor suggested we ask zoo administrators if I could return periodically to document the first year of the cub's life. They said yes.

People sometimes ask if it's exciting to shoot certain subjects. To be honest, I'm often so focused on the details of a shoot that I'm not always able to step back and find wonder in the subject alone. Instead, my mind goes to the technical: What equipment will I need? How will I handle the lighting in

> ‘DO YOU NEED AN ASSISTANT?’ THEY WOULD ASK SERIOUSLY, EAGER TO TAKE A DAY OFF FROM THEIR JOBS AS ATTORNEYS, TEACHERS, AND PARENTS.

the enclosure? How fast are panda cubs? But walking into a place where I’ll be shooting or meeting a subject for the first time is always exciting, especially when it’s happening somewhere that most people don’t get to go.

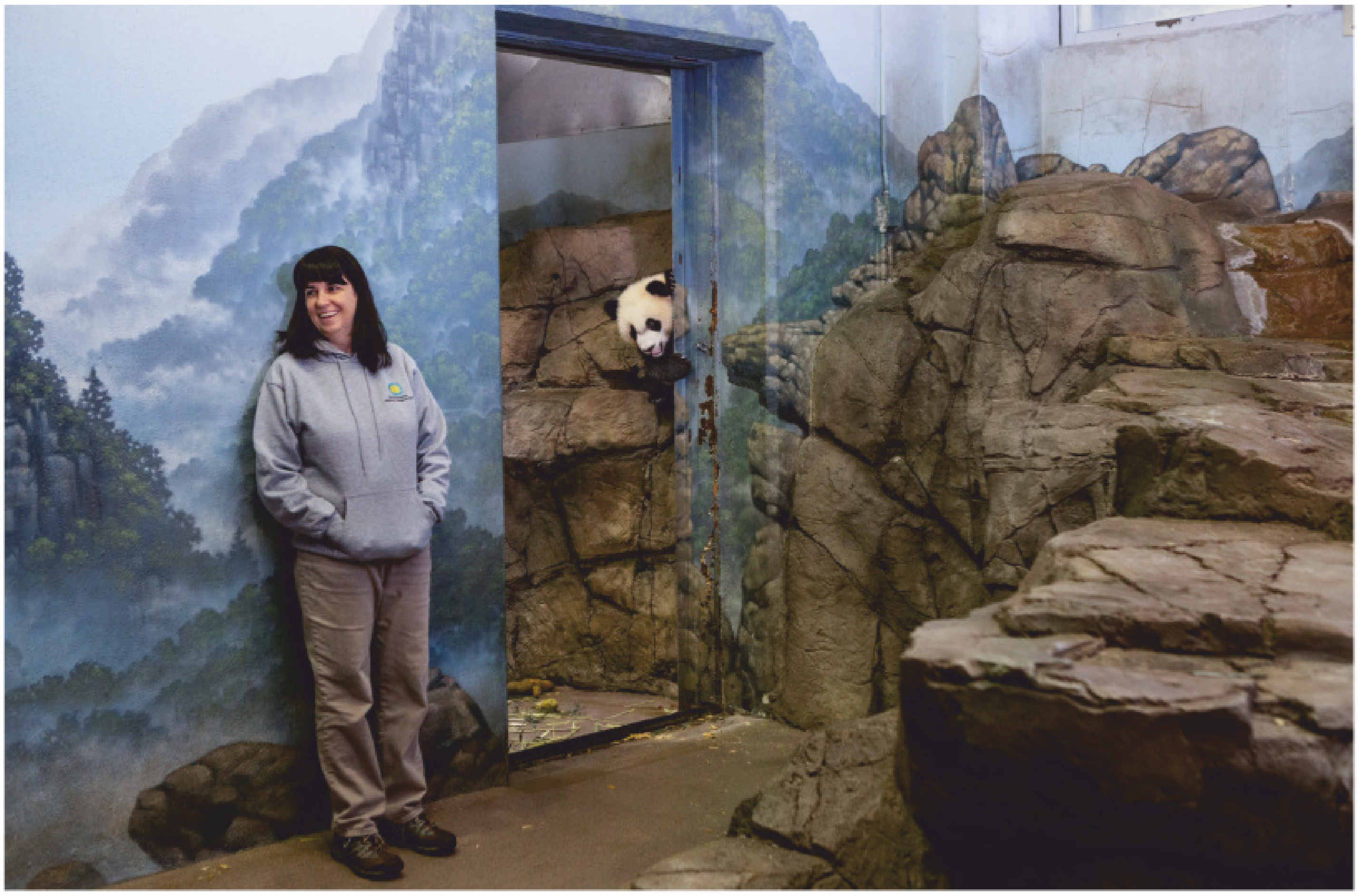
So on that first day with Bei Bei, I felt a little thrill as a zoo staffer took me down a quiet path to the back of the panda enclosure where the panda’s keepers were waiting. They introduced themselves, handed me shoe coverings and a mask, and led me through a series of gates and eventually to Bei Bei. After a moment or two of registering that an actual panda was within reach, I got to work.

Soon I was making regular stops at the zoo to record the baby panda’s transformation. I would suit up in the protective shoe coverings and face mask and make my way inside the panda enclosure before it opened to the public. I watched Bei Bei grow from a pliant cub to a curious, energetic youth. If I got too close, he’d lunge for my gear, reminding me that he was actually a bear. He played with the keepers, diving in for a back scratch or peering around the corner from one room to the next in his version of hide-and-seek. In a move dubbed panda yoga by a colleague’s young daughter, Bei Bei would navigate his enclosure, stretching precariously to get from rock to rock, as he does in the photo on the previous page. While following his routine, I spent one morning in the zoo kitchen as a keeper concocted a panda popsicle, a chunky blend of frozen fruit that looked good enough to pass muster with my own children.

My kids had never been more interested in my job than when I was on the Bei Bei beat; they were forever begging to come along. I would mention the project in passing to friends and neighbors, and they would light up in ways I’d never seen. “Do you need an assistant?” they would ask quite seriously, eager to take a day off from their jobs as attorneys, teachers, and parents. Turns out, everyone loved pandas. I was starting to develop a soft spot myself.

When Bei Bei was a few months old, the zoo held an official opening day for the public to come and see him. That morning I arrived early, making my way past the local television crews testing their lights. Past the line that was already forming at the entrance to the enclosure. Past two sisters from St. Louis who were wearing panda hats and three girls behind them who linked arms and did a high-kick routine, singing a Bei Bei tribute chant. I chatted with a woman who’d been making an annual pilgrimage to the zoo to see the pandas since 1982, panda earrings swinging enthusiastically from her ears. Yes, I told her, I live here. No, I wasn’t a tourist or visitor. I’m a Washingtonian and, yes, it is wonderful to have the zoo right here, in my backyard. My nine-year-old self would have thought that was pretty cool. □

Rebecca Hale is a staff photographer for *National Geographic*.



Bei Bei peeks through a doorway at Laurie Thompson, the assistant curator of giant pandas at the National Zoo in Washington, D.C.

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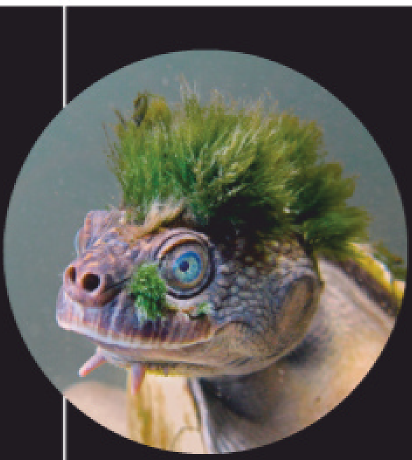
THE CURIOUS CASE OF THE 'BUM BREATHING' TURTLE

PHOTOGRAPH BY **JOEL SARTORE**

HATCHLINGS KNOWN as "penny turtles" or "pet-shop turtles" were sold in Australian stores in the 1960s and '70s. Aussie reptile expert John Cann couldn't figure out the turtle's species or origin for years—until he saw one in its only native habitat, the Mary River in Queensland. That was just the first of many intriguing discoveries about *Elusor macrurus*—the Mary River turtle, listed as endangered by the IUCN and other conservation groups.

It's one of Australia's largest freshwater turtles, topping out at nearly 18 pounds in a 17-inch-long shell. It's thought to have split from other species about 40 million years ago and is the only species in its genus. It may live to be 100 years old and not start reproducing until it's 20. And when *E. macrurus* does breed, the male deploys one part of a multipurpose tail that he also uses to void waste—and to breathe. The tail's gill-like structures allow the turtle to stay submerged for up to two and a half days without surfacing.

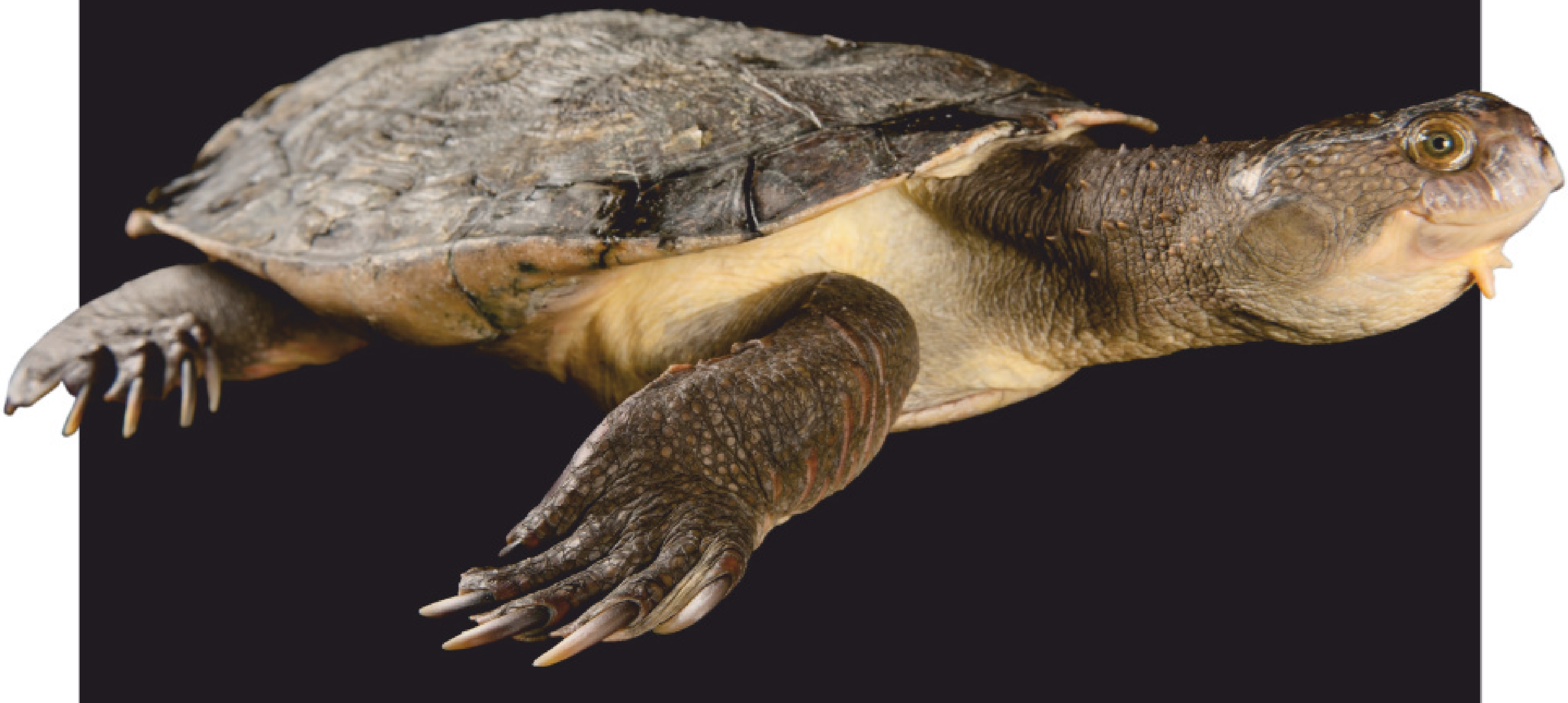
"The bum-breathing trait attracts a lot of attention," says conservationist Marilyn Connell. As a leader of the Mary River turtle conservation project in Queensland's Tiaro district, Connell is focused on preserving the species, whose population is now mostly older because predators wipe out eggs and hatchlings. In breeding season (October through December), project members prowl the riverbanks to protect nests, Connell says, so the turtle "can continue doing what it's evolved to do over eons." —PATRICIA EDMONDS



AS FOR THE COIFFURE: IT GROWS ON HIM

Chris Van Wyk opposed the Queensland government's 2006 proposal to build a dam on the Mary River, lest it damage wildlife habitat and pristine snorkeling spots. To raise awareness, the amateur photographer made pictures of at-risk animals—including the Mary River turtle, whose shock of hairlike algae is encouraged by the reptile's long stretches underwater. The "punk turtle" photos (above) went viral and pop up on the internet to this day. They also fueled the fight against the dam plan, which the government dropped in 2009. It's proof, says Van Wyk, that "photography can change the world." —PE

NATIONAL GEOGRAPHIC PHOTO ARK JOEL SARTORE



THIS MARY RIVER TURTLE WAS PHOTOGRAPHED AT THE LONE PINA KOALA SANCTUARY, QUEENSLAND, AUSTRALIA. TOP PHOTO: CHRIS VAN WYK

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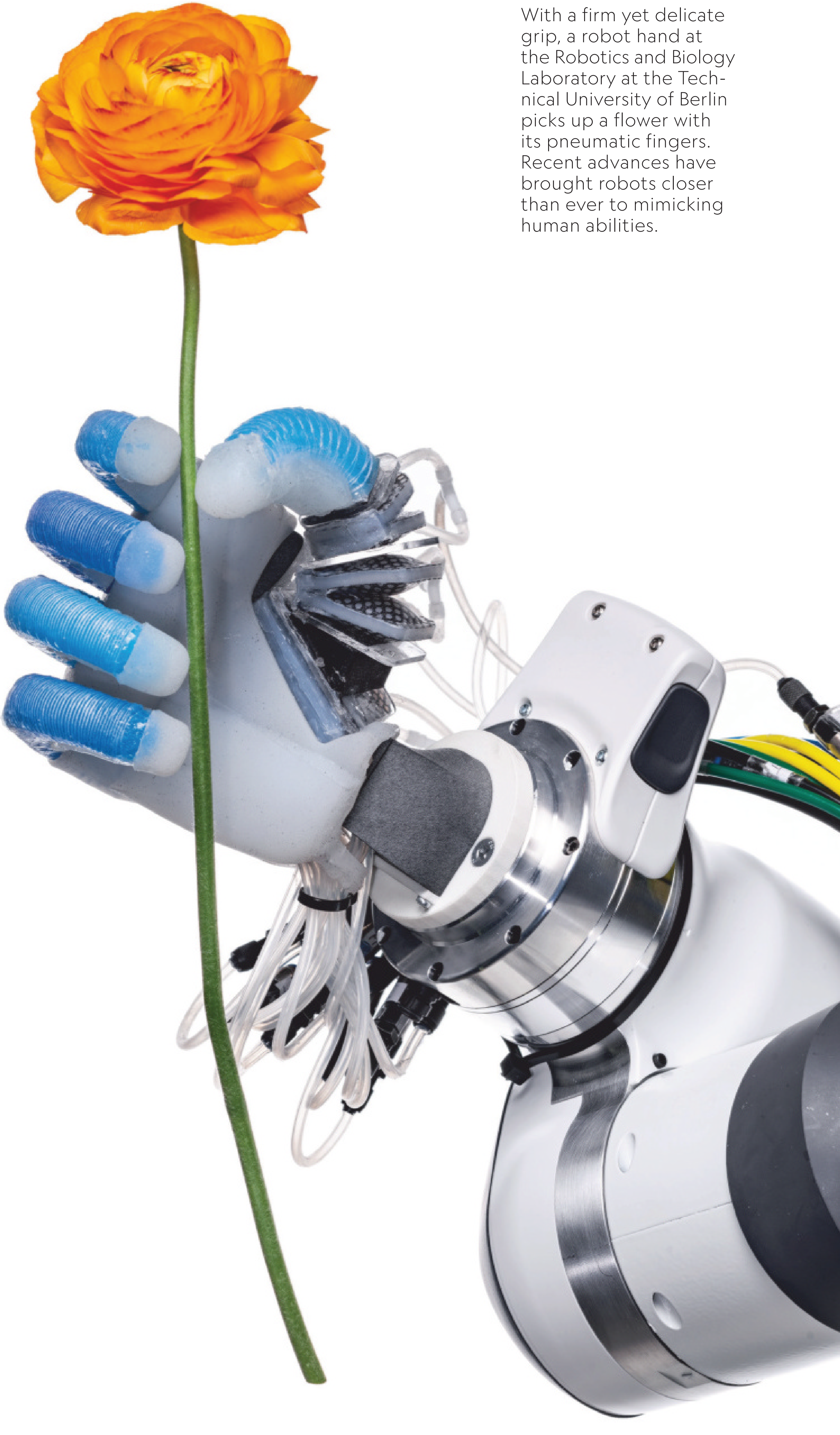
'A MERE 7 PERCENT OF THE WORLD'S OCEAN HAS ANY PROTECTION—MOSTLY WEAK RULES, WITH MULTIPLE EXCEPTIONS—AND ONLY 2.5 PERCENT IS HIGHLY PROTECTED.'

PHOTO: MANU SAN FELIX, NATIONAL GEOGRAPHIC CREATIVE

A revolution in robotics is upon us, as machines take over more duties long performed by humans. It's changing how we live.

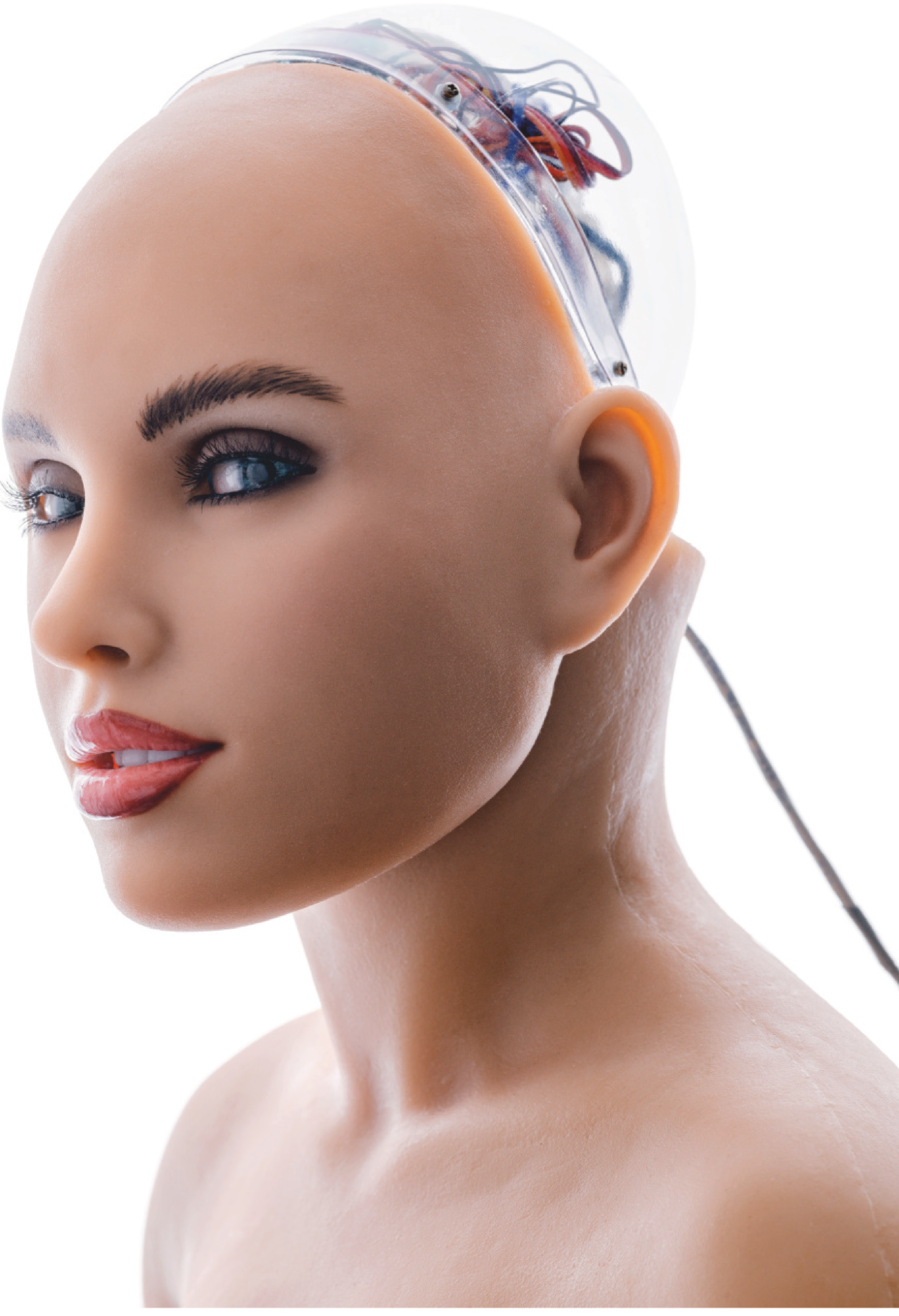
THE_ROBOTS_ARE_HERE

By **DAVID BERREBY**
Photographs by **SPENCER LOWELL**

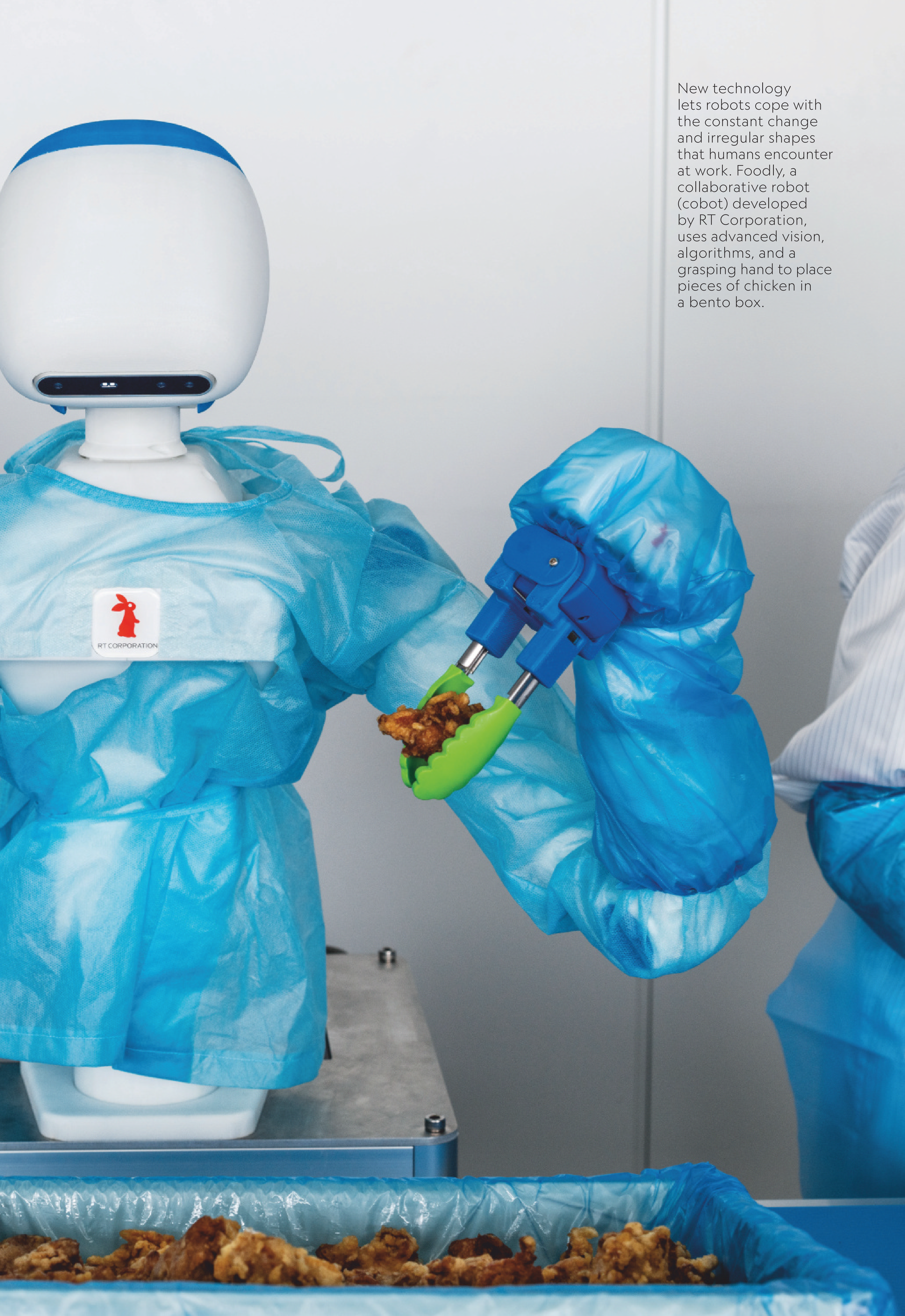


With a firm yet delicate grip, a robot hand at the Robotics and Biology Laboratory at the Technical University of Berlin picks up a flower with its pneumatic fingers. Recent advances have brought robots closer than ever to mimicking human abilities.

Some roboticists create machines that imitate humans in detail—like Harmony (right), an expressive talking head that attaches to a silicone and steel sex doll made by Abyss Creations in San Marcos, California. Others believe people are more comfortable around robots that look like Curi (left) from the



Socially Intelligent Machines Lab at Georgia Tech. If a robot seems too much like a human, they say, people's acceptance can plummet into "the uncanny valley," Masahiro Mori's term for our feelings when a robot seems less like an enhanced machine and more like a disturbingly diminished human—or a corpse.



New technology lets robots cope with the constant change and irregular shapes that humans encounter at work. Foodly, a collaborative robot (cobot) developed by RT Corporation, uses advanced vision, algorithms, and a grasping hand to place pieces of chicken in a bento box.

If you're like most people, you've probably never met a robot.

BUT YOU WILL.

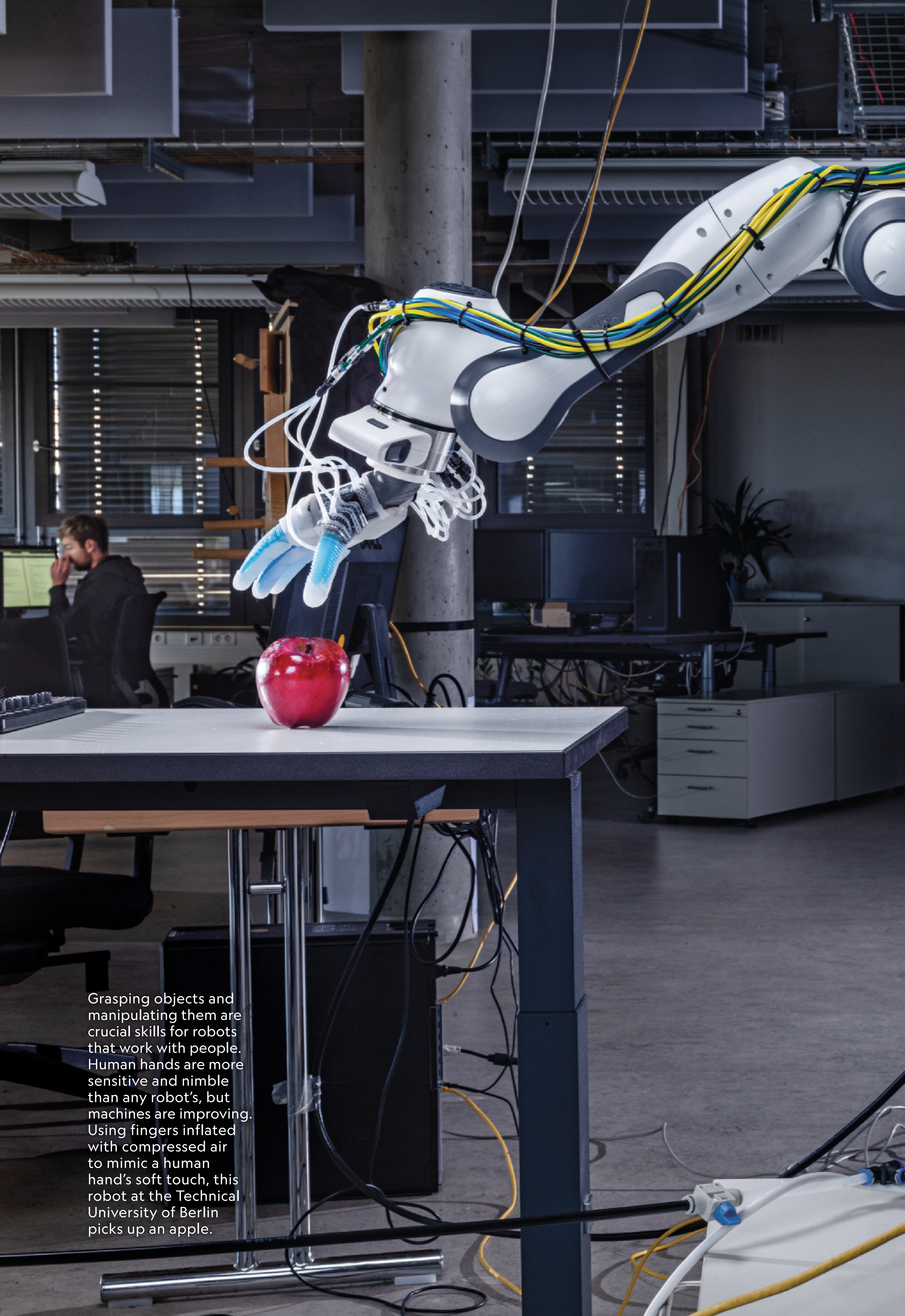
I MET ONE ON A WINDY, bright day last January, on the short-grass prairie near Colorado's border with Kansas, in the company of a rail-thin 31-year-old from San Francisco named Noah Ready-Campbell. To the south, wind turbines stretched to the horizon in uneven ranks, like a silent army of gleaming three-armed giants. In front of me was a hole that would become the foundation for another one.

A Caterpillar 336 excavator was digging that hole—62 feet in diameter, with walls that slope up at a 34-degree angle, and a floor 10 feet deep and almost perfectly level. The Cat piled the dug-up earth on a spot where it wouldn't get in the way; it would start a new pile when necessary. Every dip, dig, raise, turn, and drop of the 41-ton machine required firm control and well-tuned judgment. In North America, skilled excavator operators earn as much as $100,000 a year.

The seat in this excavator, though, was empty. The operator lay on the cab's roof. It had no hands; three snaky black cables linked it directly to the excavator's control system. It had no eyes or ears either, since it used lasers, GPS, video cameras, and gyroscope-like sensors that estimate an object's orientation in space to watch over its work. Ready-Campbell,

Some workers have wearable robots. An exoskeleton is a combination of sensors, computers, and motors that helps a human do heavy-duty work. Arms with hooks attached, demonstrated by Sarcos Robotics engineer Fletcher Garrison, can lift up to 200 pounds—perhaps to aid airport luggage handlers.

Key Result
The XO Robot Shall be easy and natural to use, following the general movement of its operator's hands, feet, pelvis and torso.
SARCOS
SARCOS
TUFF TREAD



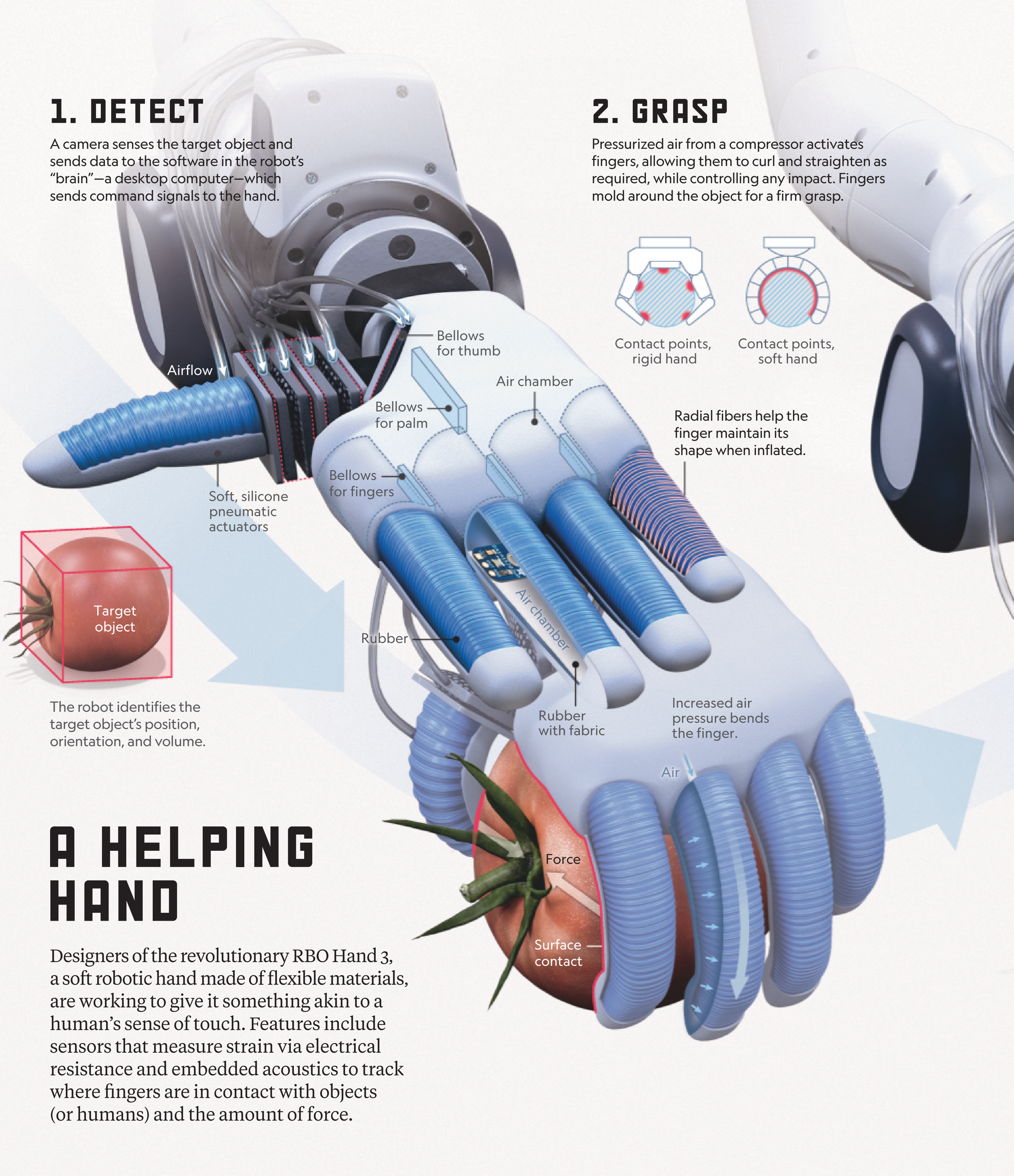
Grasping objects and manipulating them are crucial skills for robots that work with people. Human hands are more sensitive and nimble than any robot's, but machines are improving. Using fingers inflated with compressed air to mimic a human hand's soft touch, this robot at the Technical University of Berlin picks up an apple.

1. DETECT

A camera senses the target object and sends data to the software in the robot's "brain"—a desktop computer—which sends command signals to the hand.

2. GRASP

Pressurized air from a compressor activates fingers, allowing them to curl and straighten as required, while controlling any impact. Fingers mold around the object for a firm grasp.


Contact points, rigid hand
Contact points, soft hand
Bellows for thumb
Airflow
Air chamber
Bellows for palm
Bellows for fingers
Soft, silicone pneumatic actuators
Target object
Rubber
Air chamber
Rubber with fabric
Air
Force
Surface contact

Radial fibers help the finger maintain its shape when inflated.

The robot identifies the target object's position, orientation, and volume.

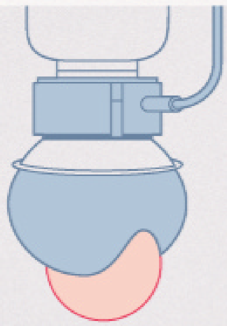
Increased air pressure bends the finger.

A HELPING HAND

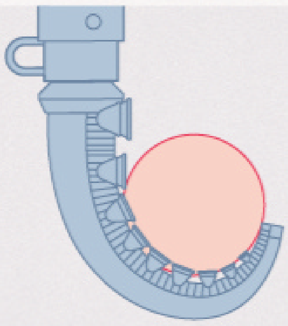
Designers of the revolutionary RBO Hand 3, a soft robotic hand made of flexible materials, are working to give it something akin to a human's sense of touch. Features include sensors that measure strain via electrical resistance and embedded acoustics to track where fingers are in contact with objects (or humans) and the amount of force.

FROM CLAWS TO TENTACLES

The human hand isn't perfectly suited for every manual task. Many robotic hands are designed to perform specialized, often repetitive tasks—some taking their design inspiration from the animal world.



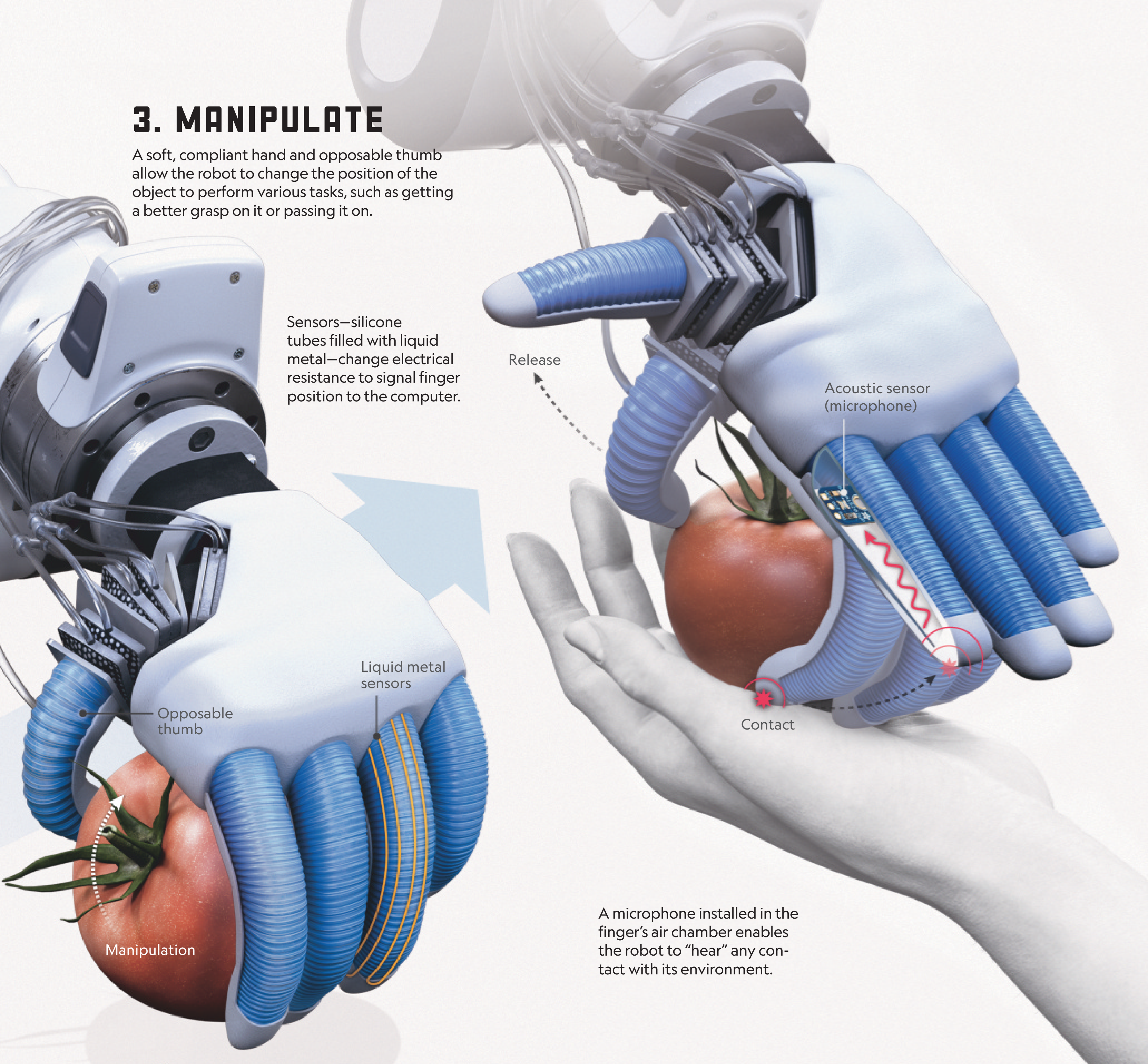
Vacuum grabber
The gripper, in its soft state, surrounds the object—then creates a vacuum to grasp it.



Gripping tentacle
The octopus-inspired gripper, with its rows of suction cups, wraps itself around an object.

3. MANIPULATE

A soft, compliant hand and opposable thumb allow the robot to change the position of the object to perform various tasks, such as getting a better grasp on it or passing it on.



Sensors—silicone tubes filled with liquid metal—change electrical resistance to signal finger position to the computer.

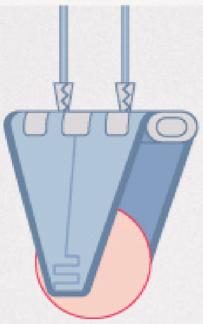
A microphone installed in the finger's air chamber enables the robot to "hear" any contact with its environment.

Centered thumb

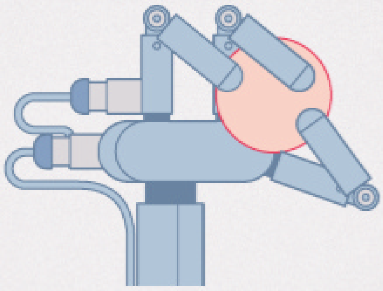
Opposable, humanlike thumbs can apply force in multiple directions for skillful manipulation.

4. INTERACT

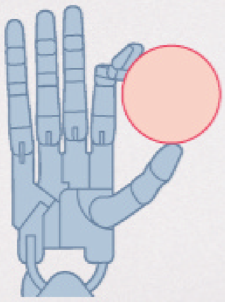
Soft robots are safer than rigid, metal ones when it comes to working with humans. Any impact or force that could harm a human is reduced by the soft materials.



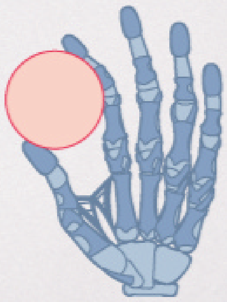
Flexible flaps
Soft, lightweight, and flexible flaps use electrostatic forces to pick up a fragile object.



High-speed claw
This robot hand—fastest on the planet—can catch an object in five-hundredths of a second.



Humanoid hand
This robot has ultrasensitive touch sensors and moves much like a human hand does.



Biomimetic hand
It mimics the human hand with artificial joint capsules and rubber ligaments and tendons.

MONICA SERRANO, NGM STAFF; KELSEY NOWAKOWSKI. ART: INTERVOKE. SOURCES: OLIVER BROCK AND STEFFEN PUHLMANN, ROBOTICS AND BIOLOGY LABORATORY, TECHNICAL UNIVERSITY OF BERLIN; JACEK SZKOPEK, GDAŃSK UNIVERSITY OF TECHNOLOGY

co-founder of a San Francisco company called Built Robotics, clomped across the coarse dirt, climbed onto the excavator, and lifted the lid of a fancy luggage carrier on the roof. Inside was his company's product—a 200-pound device that does work that once required a human being.

"This is where the AI runs," he said, pointing into the collection of circuit boards, wires, and metal boxes that made up the machine: Sensors to tell it where it is, cameras to let it see, controllers to send its commands to the excavator, communication devices that allow humans to monitor it, and the processor where its artificial intelligence, or AI, makes the decisions a human driver would. "These control signals get passed down to the computers that usually respond to the joysticks and pedals in the cab."

When I was a child in the 20th century, hoping to encounter a robot when I grew up, I expected it would look and act human, like C-3PO from *Star Wars*. Instead, the real robots that were being set up in factories were very different. Today millions of these industrial machines bolt, weld, paint, and do other repetitive, assembly-line tasks. Often fenced off to keep the remaining human workers safe, they are what roboticist Andrea Thomaz at the University of Texas has called "mute and brute" behemoths.

Ready-Campbell's device isn't like that (although the Cat did have the words "CAUTION Robotic Equipment Moves Without Warning" stamped on its side). And of course it isn't like C-3PO, either. It is, instead, a new kind of robot, far from human but still smart, adept, and mobile. Once rare, these devices—designed to "live" and work with people who have never met a robot—are migrating steadily into daily life.

Already, in 2020, robots take inventory and clean floors in Walmart. They shelve goods and fetch them for mailing in warehouses. They cut lettuce and pick apples and even raspberries. They help autistic children socialize and stroke victims regain the use of their limbs. They patrol borders and, in the case of Israel's Harop drone, attack targets they deem hostile. Robots arrange flowers, perform religious ceremonies, do stand-up comedy, and serve as sexual partners.

And that was before the COVID-19 pandemic. Suddenly, replacing people with robots—an idea majorities of people around the world dislike, according to polls—looks medically wise, if not essential.

Robots now deliver food in Milton Keynes, England, tote supplies in a Dallas hospital, disinfect patients' rooms in China and Europe, and wander parks in Singapore, nagging pedestrians to maintain social distance.

ROBOTS TAKE INVENTORY

and clean at big stores. They patrol borders, perform religious ceremonies,

AND HELP AUTISTIC CHILDREN.

This past spring, in the middle of a global economic collapse, the robotmakers I'd contacted in 2019, when I started working on this article, said they were getting more, not fewer, inquiries from potential customers. The pandemic has made more people realize that "automation is going to be a part of work," Ready-Campbell told me in May. "The driver of that had been efficiency and productivity, but now there's this other layer to it, which is health and safety."

Even before the COVID crisis added its impetus, technological trends were accelerating the creation of robots that could fan out into our lives. Mechanical parts got lighter, cheaper, and sturdier. Electronics packed more computing power into smaller packages. Breakthroughs let engineers put powerful data-crunching tools into robot bodies. Better digital communications let them keep some robot "brains" in a computer elsewhere—or connect a simple robot to hundreds of others, letting them share a collective intelligence, like a beehive's.

The workplace of the near future "will be an ecosystem of humans and robots working together to maximize efficiency," said Ahti Heinla, co-founder of the Skype internet-call platform, now co-founder and chief technology officer of Starship Technologies, whose six-wheeled, self-driving delivery robots are rolling around Milton Keynes and other cities in Europe and the United States.

"We've gotten used to having machine intelligence that we can carry around with us," said Manuela Veloso, an AI roboticist at Carnegie Mellon University in Pittsburgh. She held up her smartphone. "Now we're going to have to get used to intelligence that has a body and moves around without us."

Outside her office, her team's "cobots"—collaborative robots—roam the halls, guiding visitors and delivering paperwork. They look like iPads on wheeled display stands. But they move about on their own, even taking elevators when they need to (they beep and flash a polite request to nearby humans to push the buttons for them).

"It's an inevitable fact that we are going to have machines, artificial creatures, that will be a part of our daily life," Veloso said. "When you start accepting robots around you, like a third species, along with pets and humans, you want to relate to them."

We're all going to have to figure out how. "People have to understand that this isn't science fiction; it's not something that's going to happen 20 years from now," Veloso said. "It's started to happen."

VIDAL PÉREZ LIKES his new co-worker.

For seven years, working for Taylor Farms in Salinas, California, the 34-year-old used a seven-inch knife to cut lettuce. Bending at the waist, over and over, he would slice off a head of romaine or iceberg, shear off imperfect leaves, and toss it into a bin.

Since 2016, though, a robot has done the slicing. It's a 28-foot-long, tractorlike harvester that moves steadily down the rows in a cloud of mist from the high-pressure water jet it uses to cut off a lettuce head every time its sensor detects one. The cut lettuce falls onto a sloped conveyor belt that carries it up to the harvester's platform, where a team of about 20 workers sorts it into bins.

I met Pérez early one morning in June 2019, as he took a break from working a 22-acre field of romaine destined for Taylor's fast-food and grocery store customers. A couple hundred yards away, another crew of lettuce cutters hunched over the plants, knives flashing as they worked in the old pre-robot style.

"This is better, because you get a lot more tired cutting lettuce with a knife than with this machine," Pérez said. Riding on the robot, he rotates bins on the conveyor belt. Not all the workers prefer the new system, he said. "Some people want to stay with what they know. And some get bored with standing on the machine, since they're used to moving all the time through a field."

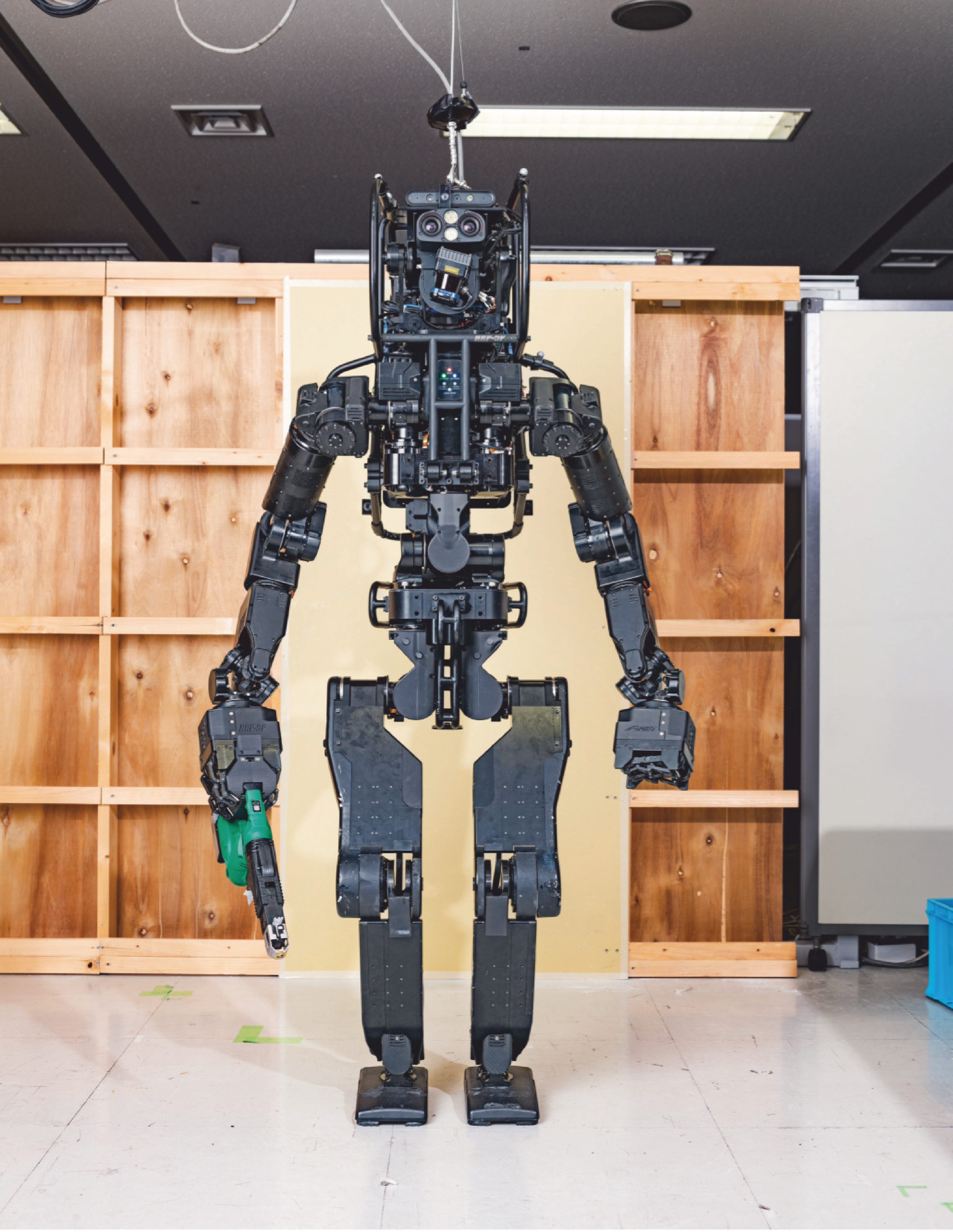
Taylor Farms is one of the first major California agricultural companies to invest in robotic farming. "We're going through a generational change ... in agriculture," Taylor Farms California president Mark Borman told me while we drove from the field in his pickup. As older workers leave, younger people aren't choosing to fill the backbreaking jobs. A worldwide turn toward restrictions on cross-border migration, accelerated by COVID fears, hasn't helped either. Farming around the world is being roboticized, Borman said. "We're growing, our workforce is shrinking, so robots present an opportunity that's good for both of us."

It was a refrain I heard often last year from employers in farming and construction, manufacturing and health care: We're giving tasks to robots because we can't find people to do them.

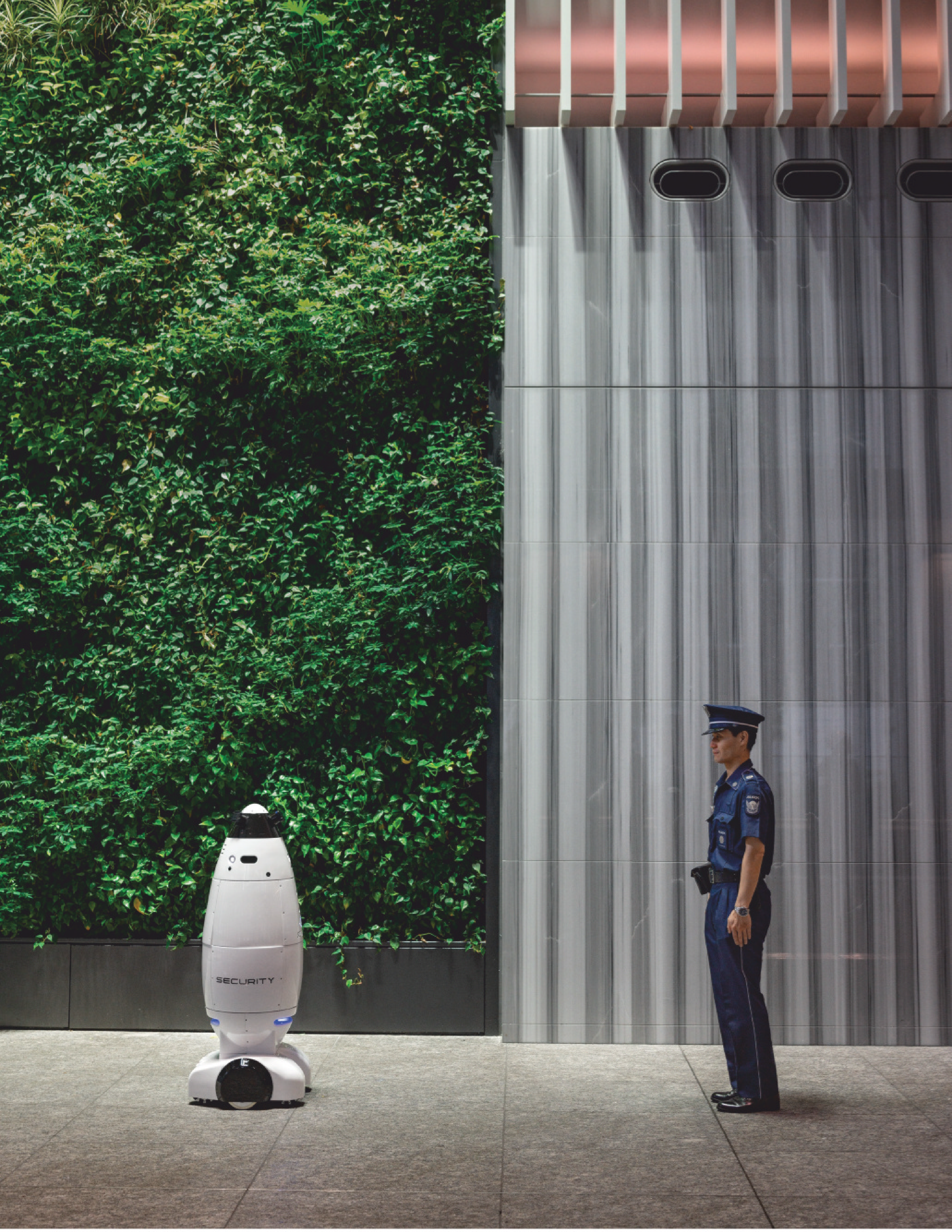
At the wind farm site in Colorado, executives from the Mortenson Company, a Minneapolis-based construction firm that has hired Built's robots since 2018, told me about a dire shortage of skilled workers in their industry. Built robots dug 21 foundations at the wind farm.

"Operators will say things like, Oh, hey, here come the job killers," said Derek Smith, lean innovation manager for Mortenson. "But after they see that the robot takes away a lot of repetitive work and they still have plenty to do, that shifts pretty quickly."

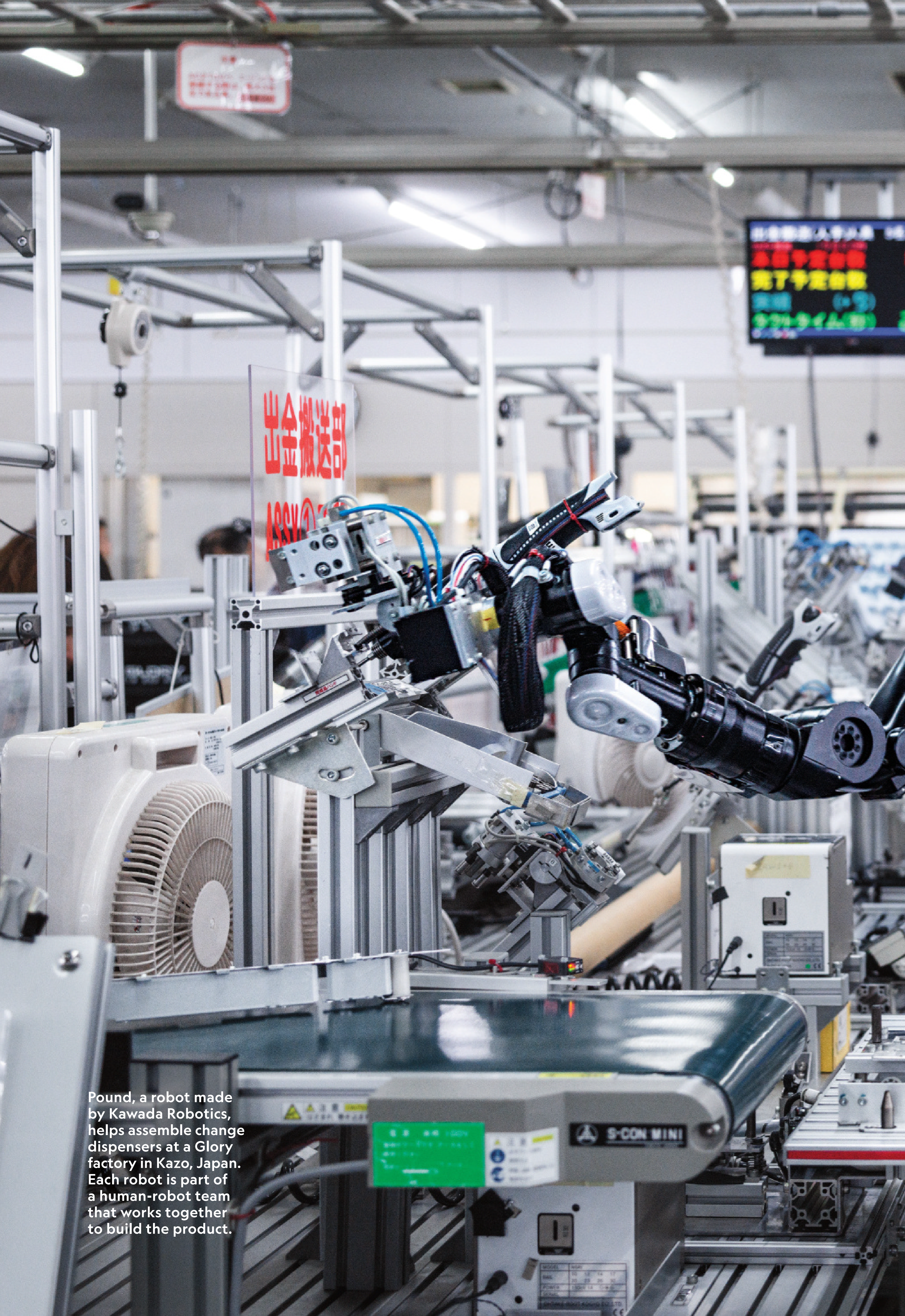
Once the robot excavator finished the dig we'd watched, a human on a bulldozer smoothed out the work and made ramps. "On this job, we have



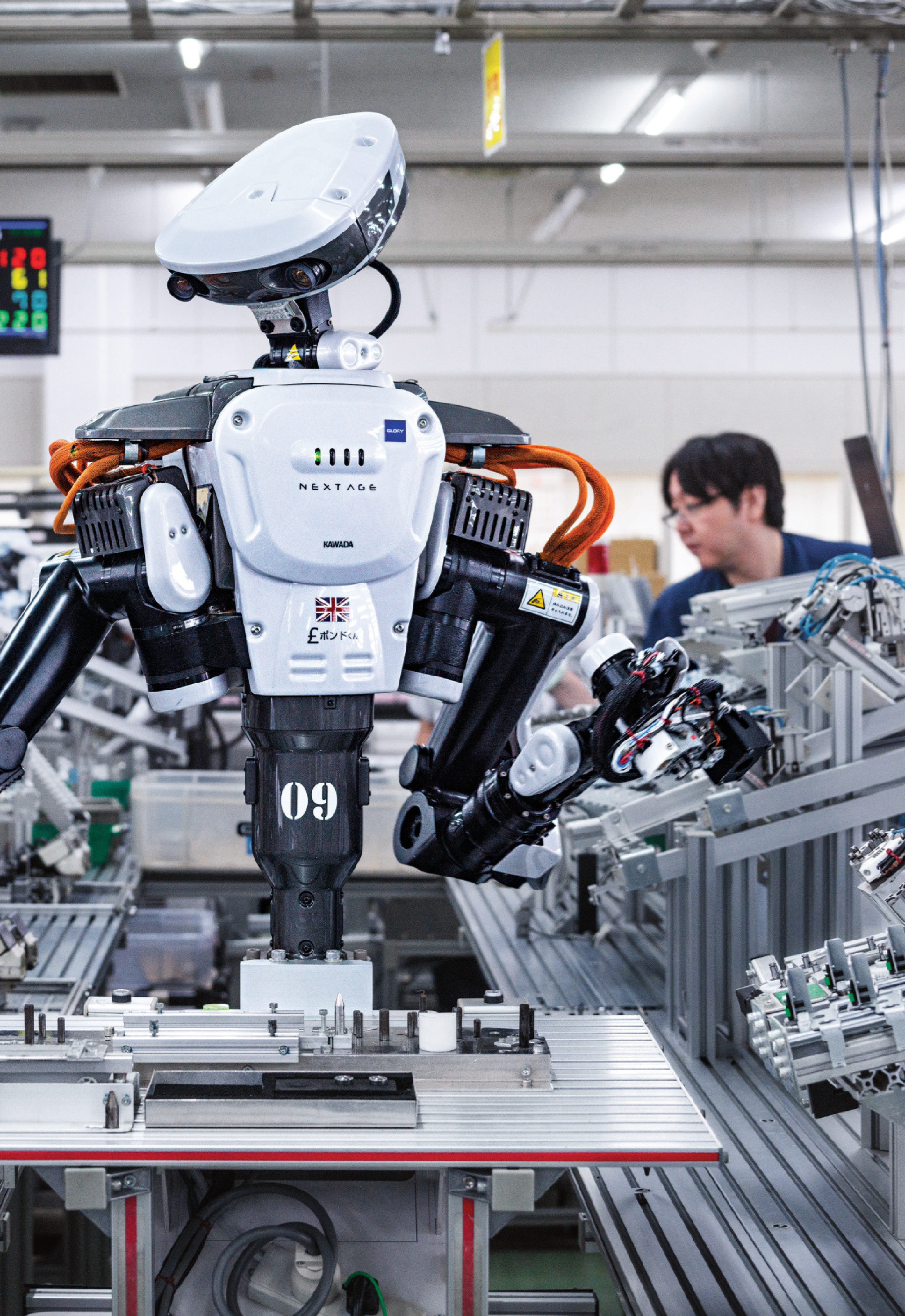
Designers shape each robot according to its duties—and the needs of people it works with. The five-foot-nine-inch, 222-pound HRP-5P (left), developed at Japan's National Institute of Advanced Industrial Science and Technology, has arms, legs, and a head and handles heavy loads in places such as



construction sites and shipyards. In contrast, SQ-2, a security robot (right), is limbless and quietly unassuming at slightly more than four feet tall and 143 pounds. Its shape accommodates a 360-degree camera, a laser mapping system, and a computer that allows the robot to patrol on its own.



Pound, a robot made by Kawada Robotics, helps assemble change dispensers at a Glory factory in Kazo, Japan. Each robot is part of a human-robot team that works together to build the product.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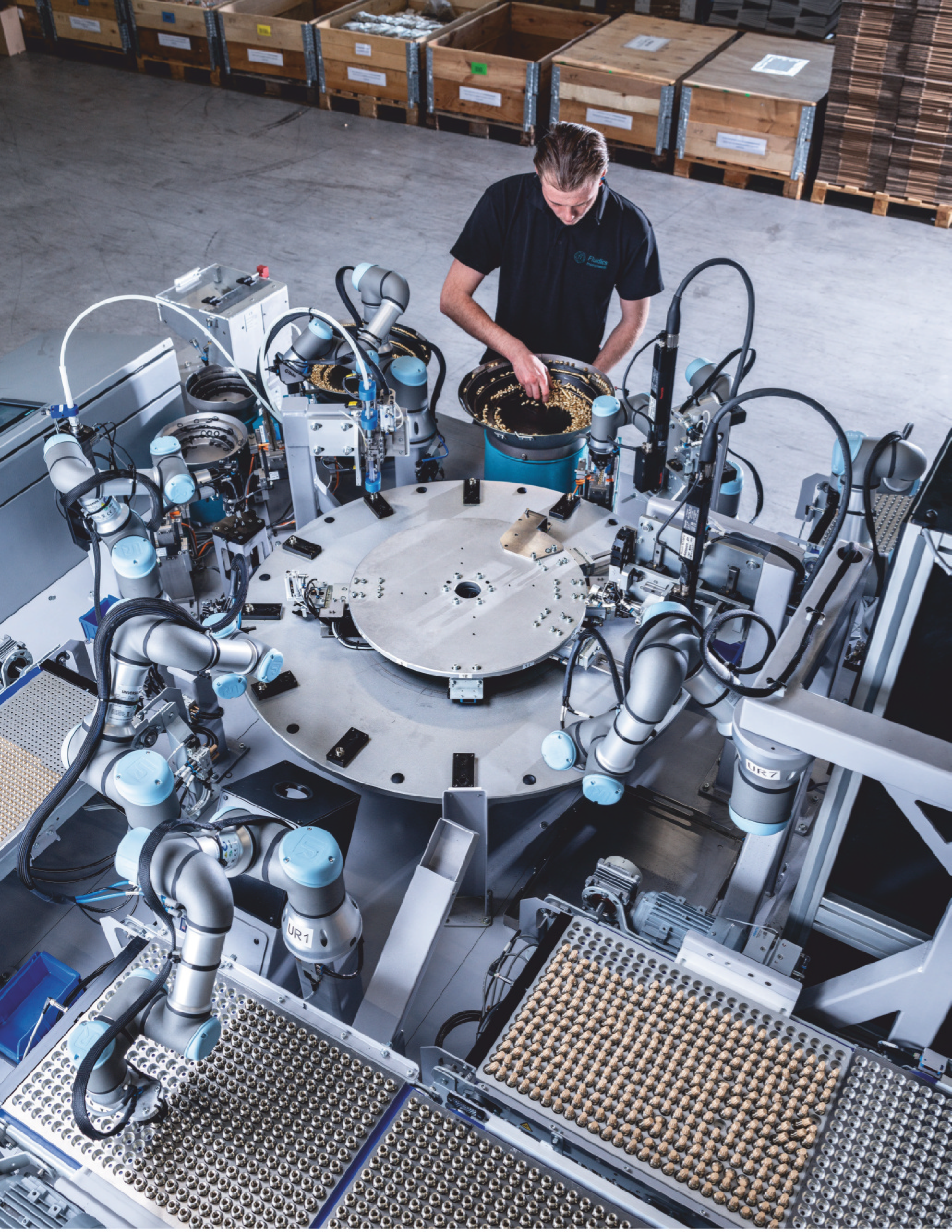


Robot partners come in many forms. At Fluidics Instruments in Eindhoven, Netherlands (left), an employee works with seven robot arms to assemble parts for oil and gas burners. Like traditional factory robots, these cobots are efficient and precise—able to produce a thousand nozzles an hour. But unlike

Medical City Healthcare
fetchrobotics

older machines, they adapt quickly to changed specs or a new task. At Medical City Heart Hospital in Dallas (right), nurses work with Moxi, a robot built to learn and then perform tasks that take nurses away from patients, such as fetching supplies, delivering lab samples, and removing bags of soiled linens.

229 foundations, and every one is basically the same spec," Smith said. "We want to take away tasks that are repetitive. Then our operators concentrate on the tasks that involve more art."

The pandemic's tsunami of job losses hasn't changed this outlook, robotmakers and users told me. "Even with a very high unemployment rate, you can't just snap your fingers and fill jobs that need highly specialized skills, because we don't have the people that have the training," said Ben Wolff, chairman and CEO of Sarcos Robotics.

The Utah-based firm makes wearable robots called exoskeletons, which add the strength and precision of a machine to a worker's movements. Delta Air Lines had just begun to test a Sarcos device with aircraft mechanics when the pandemic decimated air travel.

When I reached Wolff last spring, he was upbeat. "There is a short-term slowdown, but long term we expect more business," he said.

Most employers are now looking to reduce contact among employees, and a device that lets one do the work of two might help. Since the pandemic began, Wolff told me, Sarcos has seen a jump in inquiries, some from companies he didn't expect—for example, a major electronics firm, a pharmaceutical company, a meat-packer. The electronics- and pillmakers wanted to move heavy supplies with fewer people. The meat-packer was interested in spreading out its crowded workers.

In a world that now fears human contact, it won't be easy to fill jobs caring for children or the elderly. Maja Matarić, a computer scientist and roboticist at the University of Southern California, develops "socially assistive robots"—machines that do social support rather than physical labor. One of her lab's projects, for example, is a robot coach that leads an elderly user through an exercise routine, then encourages the human to go outside and walk.

"It says, 'I can't go outside, but why don't you take a walk and tell me about it?' " Matarić told me. The robot is a white plastic head, torso, and arms that sits atop a rolling metal stand. But its sensors and software allow it to do some of what a human coach would do—for example, saying, "Bend your left forearm inward a little," during exercise, or "Nice job!" afterward.

We walked around her lab—a warren of young people in cubicles, working on the technologies that might let a robot help keep the conversation going in a support group, for example, or respond in a way that makes a human feel like the machine is empathizing. I asked Matarić if people ever got creeped out at the thought of a machine watching over Grandpa.

"We're not replacing caregivers," she said. "We're filling a gap. Grown-up children can't be there with elderly parents. And the people who take care of other people in this country are underpaid and underappreciated. Until that changes, using robots is what we'll have to do."

DAYS AFTER I VISITED Matarić's lab, in a different world 20 miles due south of the university, hundreds of longshoremen were marching against robots. This was in the San Pedro section of Los Angeles, where container cranes tower over a landscape of warehouses and docks and modest residential streets. Generations of people in this tight-knit community have worked as longshoremen on the docks. The current generation didn't like a plan to bring robot cargo handlers to the port's largest terminal, even though such machines already are common in ports worldwide, including others in the Los Angeles area.

The dockworkers don't expect the world to stop changing, said Joe Buscaino, who represents San Pedro on the Los Angeles City Council. San Pedro has gone through economic upheavals before, as fishing, canning, and shipbuilding boomed and busted. The problem with robots, Buscaino told me, is the speed with which employers are dropping them into workers' lives.

"Years ago my dad saw that fishing was coming to an end, so he got a job in a bakery," he said. "He was able to transition. But automation has the ability to take jobs overnight."

Economists disagree a great deal about how much and how soon robots will affect future jobs. But many experts do agree on one thing: Some workers will have a much harder time adapting to robots.

"The evidence is fairly clear that we have many, many fewer blue-collar production jobs, assembly jobs, in industries that are adopting robots," said Daron Acemoglu, an economist at MIT who has studied the effects of robots and other automation. "That doesn't mean that future technology cannot create jobs. But the notion that we’re going to adopt automation technologies left, right, and center and also create lots of jobs is a purposefully misleading and incorrect fantasy.”

For all the optimism of investors, researchers, and entrepreneurs at start-ups, many people, such as Buscaino, worry about a future full of robots. They fear robots won’t take over just grunt work but the whole job, or at least the parts of it that are challenging, honorable—and well paid. (The latter process is prevalent enough that economists have a name for it: “de-skilling.”) People also fear robots will make work more stressful, perhaps even more dangerous.

> **‘THIS ISN’T SCIENCE FICTION.**
>
> *It’s not something that’s going to happen 20 years from now.*
>
> **IT’S STARTED.’**
>
> —Manuela Veloso, Carnegie Mellon AI roboticist

Beth Gutelius, an urban planner and economist at the University of Illinois at Chicago who has researched the warehouse industry, told me about one warehouse she visited after it introduced robots. The robots were quickly delivering goods to humans for packing, and this was saving the workers a lot of walking back and forth. It also made them feel rushed and eliminated their chance to speak to one another.

Employers should consider that this kind of stress on employees “is not healthy, and it’s real, and it has impacts on the well-being of the workers,” said Dawn Castillo, an epidemiologist who manages occupational robot research at the National Institute for Occupational Safety and Health at the CDC. The Center for Occupational Robotics Research actually expects robot-related deaths “will likely increase over time,” according to its website. This is because there are more robots in more places with each passing year, but also because robots are working in new settings—where they meet people who don’t know what to expect and situations that their designers didn’t necessarily anticipate.

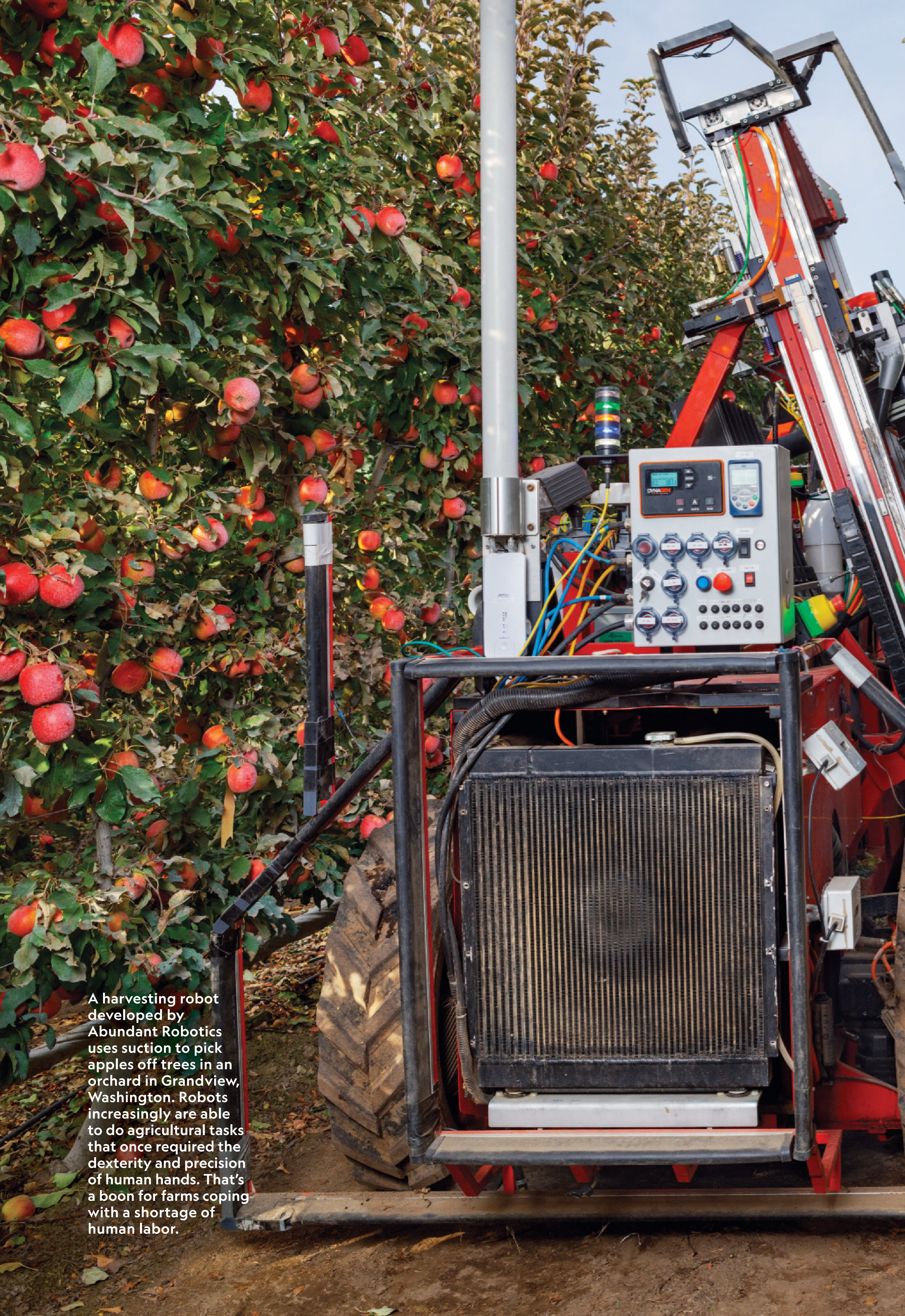
In San Pedro, after Buscaino won a city council vote to block the automation plan, the International Longshore and Warehouse Union negotiated what the union’s local chapter president called a “bittersweet” deal with Maersk, the Danish conglomerate that operates the container terminal. The dockworkers agreed to end the fight against robots in exchange for 450 mechanics getting “upskilled”: trained to work on the robots. Another 450 workers will be “reskilled”: trained to work at new, tech-friendly jobs.

How effective all that retraining will be, especially for middle-aged workers, remains to be seen, Buscaino said. A friend of his is a mechanic, whose background with cars and trucks leaves him well positioned to add robot maintenance to his skills. On the other hand, “my brother-in-law Dominic, who is a longshoreman today, he has no clue how to work on these robots. And he’s 56.”

THE WORD “ROBOT” IS PRECISELY 100 years old this year. It was coined by the Czech writer Karel Čapek, in a play that set the template for a century’s machine dreams and nightmares. The robots in that play, *R.U.R.*, look and act like people, do all the work of humans—and wipe out the human race before the curtain falls.

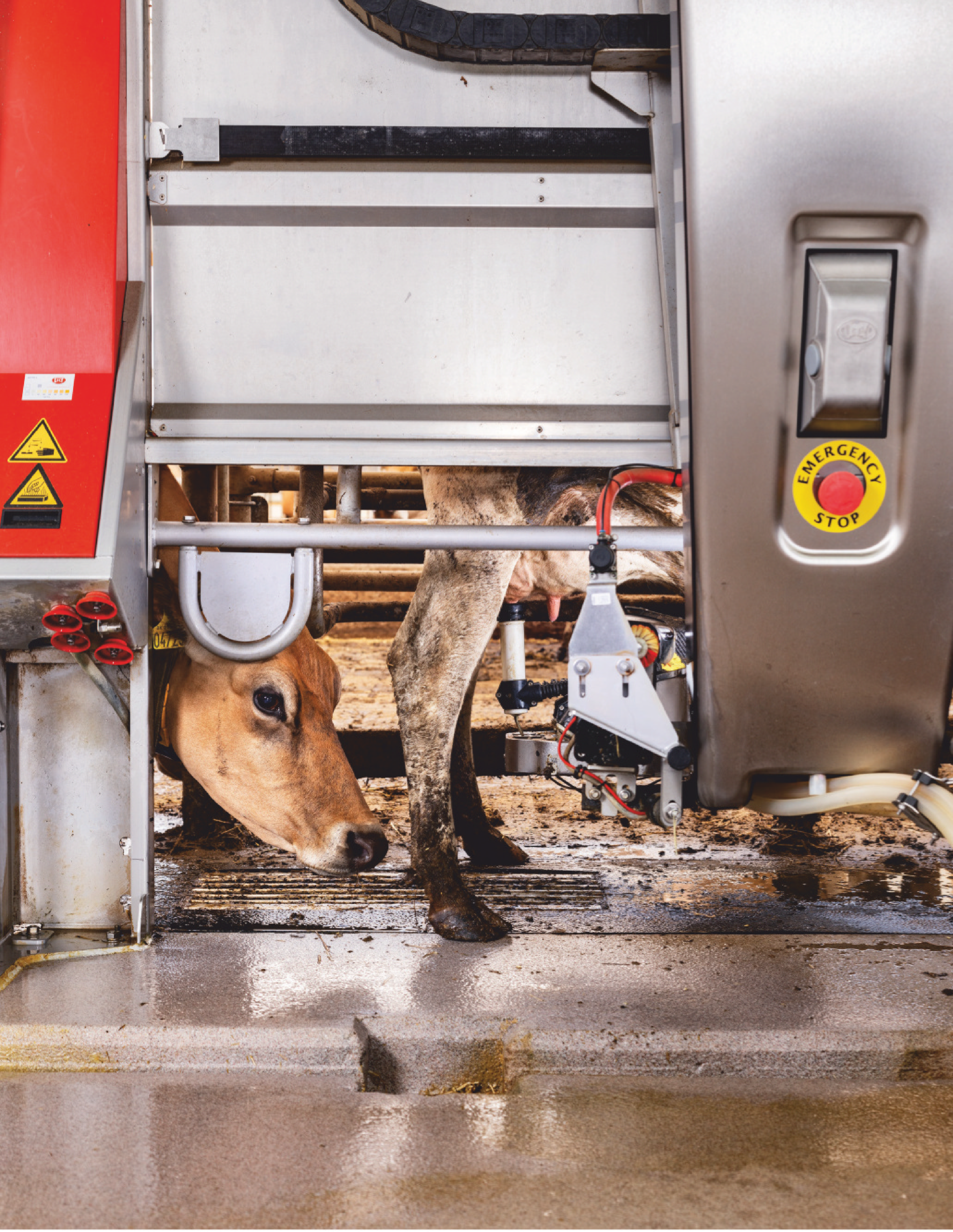
Ever since, imaginary robots from the *Terminator* to Japan’s *Astro Boy* to those *Star Wars* droids have had a huge influence on the plans of robotmakers. They also have shaped the public’s expectations of what robots are and what they can do.

Tensho Goto is a monk in the Rinzai school of Japanese Zen Buddhism. A vigorous, sturdy man with a cheerful manner, Goto met me in a spare, elegant room at Kodai-ji, the 17th-century temple in Kyoto where he is the chief steward. He seemed the picture of tradition. Yet he has



A harvesting robot developed by Abundant Robotics uses suction to pick apples off trees in an orchard in Grandview, Washington. Robots increasingly are able to do agricultural tasks that once required the dexterity and precision of human hands. That's a boon for farms coping with a shortage of human labor.

Every hour at Nursery Waalzicht in Poederoijen, Netherlands (left), three robots made by ISO Group plant 18,000 flower plugs—seedlings that have just begun to grow—supervised by a single human worker. At Henri Willig farm in Katwoude, Netherlands (right), a cow decides to enter a Lely Astronaut



A4 robot. When the animal walks up, the robot scans her collar and gives her a treat if she's right about needing to be milked (if she's not, she gets no treat and walks on). The machine does the milking automatically. Farmers monitor production and give the robot instructions via a touchpad.

been dreaming of robots for many years. It began decades ago, when he read about artificial minds and thought about reproducing the Buddha himself in silicone, plastic, and metal. With android versions of the sages, he said, Buddhists could "hear their words directly."

Once he began collaborating with roboticists at Osaka University, though, robot reality dampened the robot dream. He learned that "as AI technology exists today, it is impossible to create human intelligence, let alone the personages of those who have attained enlightenment." But like many roboticists, he didn't give up, instead settling for what is possible today.

It stands at one end of a white-walled room on the temple grounds: a metal and silicone incarnation of Kannon, the deity who in Japanese Buddhism embodies compassion and mercy. For centuries, temples and shrines have used statues to attract people and get them to focus on Buddhist tenets. "Now, for the first time, a statue moves," Goto said.

Mindar, as the robot is called, delivers prerecorded sermons in a forceful, not-quite-human female voice, gently gesticulating with her arms and turning her head from side to side to survey the audience. When her eyes fall on you, you feel something—but it isn't her intelligence. There is no AI in Mindar. Goto hopes that will change over time, and that his moving statue will become capable of holding conversations with people and answering their religious questions.

Across the Pacific, in a nondescript house in a quiet suburb of San Diego, I met a man who seeks to provide a different kind of intimate experience with robots. Artist Matt McMullen is CEO of a company called Abyss Creations, which makes realistic, life-size sex dolls. McMullen leads a team of programmers, robotics specialists, special-effects experts, engineers, and artists who create robot companions that can appeal to hearts and minds as well as sex organs.

The company has made silicone-skin, steel-skeleton RealDolls for more than a decade. They go for about $4,000. But these days, for an additional $8,000, a customer receives a robotic head packed with electronics that power facial expressions, a voice, and an artificial intelligence that can be programmed via a smartphone app.

Like Siri or Alexa, the doll's AI gets to know the user via the commands and questions he or she gives it. Below the neck, for now, the robot is still a doll—its arms and legs move only when the user manipulates them.

GETTING SMARTER

Some of the earliest robots of the mid-20th century were devices mostly controlled by nearby humans or were simple tools able to perform limited tasks.

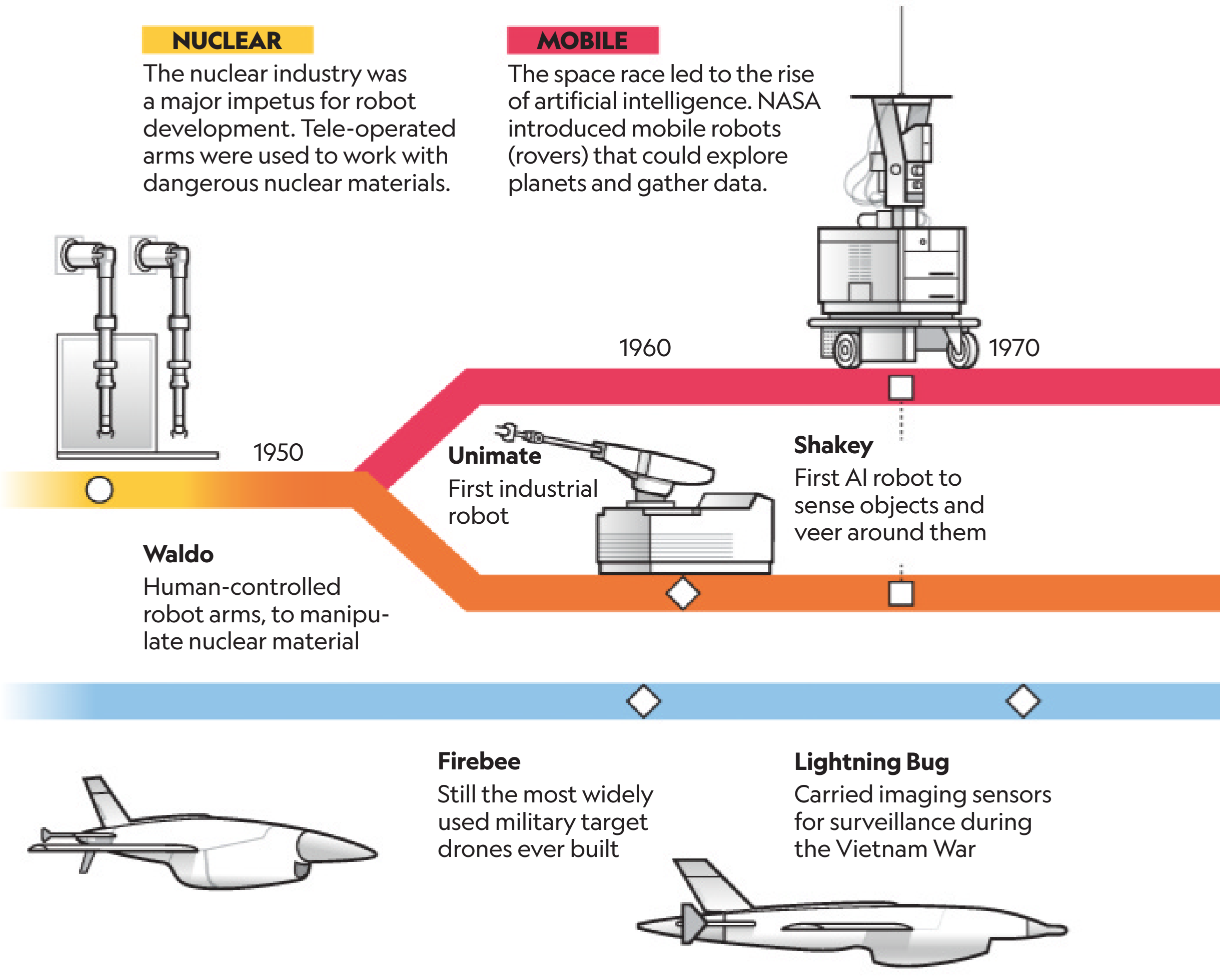
Robot autonomy

○ Remotely operated

◇ Automated

□ Artificial Intelligence

Year marks date of commercialization or extensive use. Illustrations are not to scale.



NUCLEAR
The nuclear industry was a major impetus for robot development. Tele-operated arms were used to work with dangerous nuclear materials.

MOBILE
The space race led to the rise of artificial intelligence. NASA introduced mobile robots (rovers) that could explore planets and gather data.

Waldo
Human-controlled robot arms, to manipulate nuclear material

Unimate
First industrial robot

Shakey
First AI robot to sense objects and veer around them

Firebee
Still the most widely used military target drones ever built

Lightning Bug
Carried imaging sensors for surveillance during the Vietnam War

"We don't today have a real artificial intelligence that resembles a human mind," McMullen acknowledges. "But I think we will. I think that is inevitable." He has no doubt the market is there. "I think there are people who can greatly benefit from robots that look like people," he said.

WE ARE GETTING ATTACHED already to ones that don't look much like us at all.

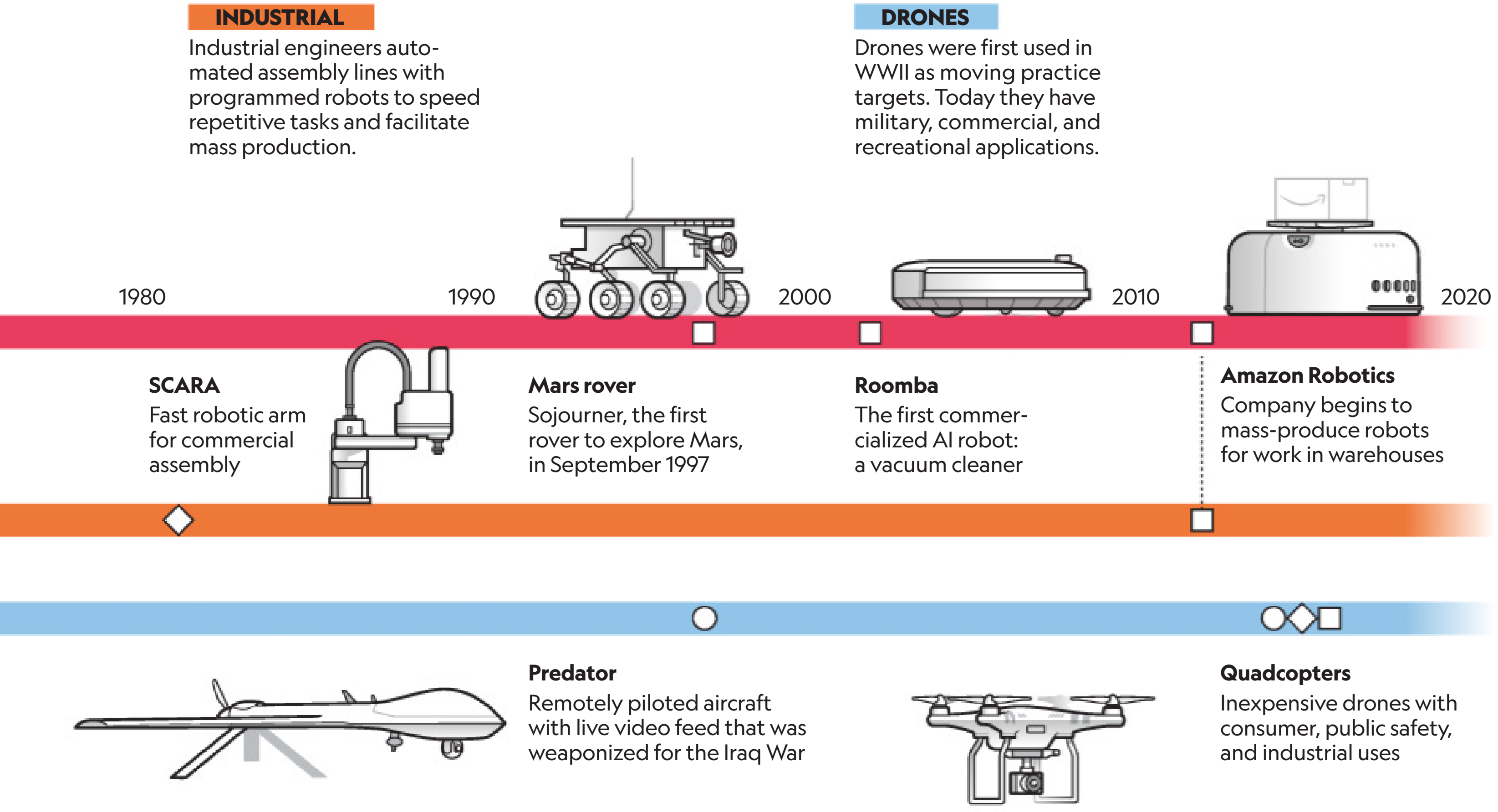
Military units have held funerals for bomb-clearing robots blown up in action. Nurses in hospitals tease their robot colleagues. People in experiments have declined to rat out their robot teammates. As robots get more lifelike, people probably will invest them with even more affection and trust—too much, perhaps. The influence of fantasy robots leads people to think that today's real machines are far more capable than they really are. Adapting well to their presence among us, experts told me, must start with realistic expectations.

Robots can be programmed or trained to do a well-defined task—dig a foundation, harvest lettuce—better or at least more consistently than humans can. But none can equal the human mind's ability to do a lot of different tasks, especially unexpected ones. None has yet mastered common sense.

Today's robots can't match human hands either, said Chico Marks, a manufacturing engineering manager at Subaru's auto plant in Lafayette, Indiana. The plant, like those of all carmakers, has used standard industrial robots for decades. It's now gradually adding new types, for tasks such as moving self-guided carts that take parts around the plant. Marks showed me a combination of wires that would snake through a curving section near a future car's rear door.

"Routing a wiring harness into a vehicle is not something that lends itself well to automation," Marks said. "It requires a human brain and tactile feedback to know it's in the right place and connected."

Robot legs aren't any better. In 1996 Veloso, the Carnegie Mellon AI roboticist, was part of a challenge to create robots that would play soccer better than humans by 2050. She was one of a group of researchers that year who created the RoboCup tournament to spur progress. Today



INDUSTRIAL

Industrial engineers automated assembly lines with programmed robots to speed repetitive tasks and facilitate mass production.

DRONES

Drones were first used in WWII as moving practice targets. Today they have military, commercial, and recreational applications.

SCARA
Fast robotic arm for commercial assembly

Mars rover
Sojourner, the first rover to explore Mars, in September 1997

Roomba
The first commercialized AI robot: a vacuum cleaner

Amazon Robotics
Company begins to mass-produce robots for work in warehouses

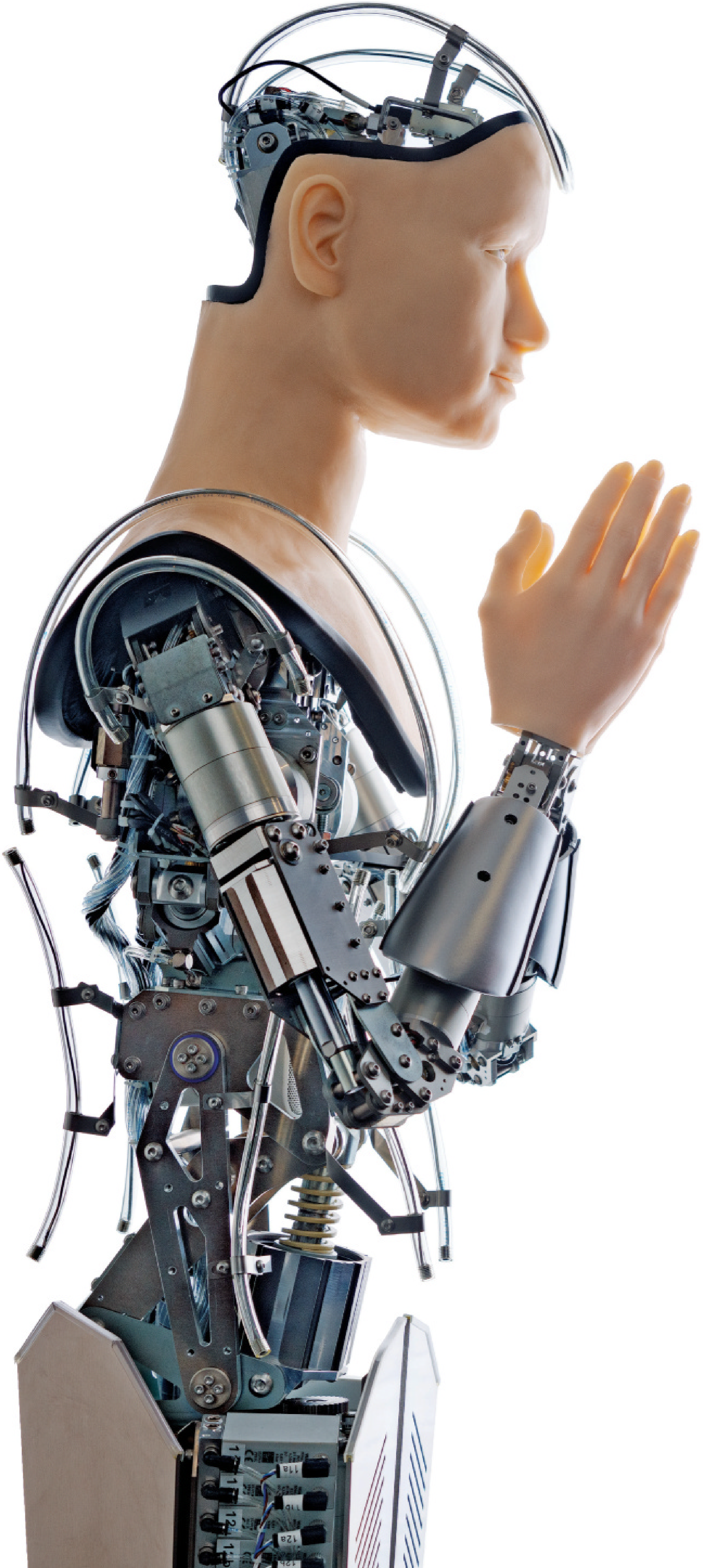
Predator
Remotely piloted aircraft with live video feed that was weaponized for the Iraq War

Quadcopters
Inexpensive drones with consumer, public safety, and industrial uses

MONICA SERRANO, NGM STAFF; KELSEY NOWAKOWSKI. ART: MATTHEW TWOMBLY. SOURCE: ROBIN MURPHY, TEXAS A&M

ANYmal, a robot that can climb stairs, step delicately over debris, or crawl through tight spaces, strolls on a street near the offices of its maker, ANYbotics, in Zurich, Switzerland. Unlike wheeled robots, legged devices such as ANYmal can go almost anywhere people can—and places where they can't, like areas contaminated by radioactive or chemical wastes.

Weinbergstrasse
Leonhardstrasse
ANYmal



Mindar—a robotic incarnation of Kannon, the deity of mercy and compassion in Japanese Buddhism—faces Tensho Goto, a monk at the Kodai-ji temple in Kyoto, Japan. Mindar, created by a team led by roboticist Hiroshi Ishiguro of Osaka University, can recite Buddhist teachings.

RoboCup is a well-loved tradition for engineers on several continents, but no one, including Veloso, expects robots to play soccer better than humans anytime soon.

“It’s crazy how sophisticated our bodies are as machines,” she said. “We’re very good at handling gravity, dealing with forces as we walk, being pushed and keeping our balance. It’s going to be many years before a bipedal robot can walk as well as a person.”

Robots are not going to be artificial people. We need to adapt to them, as Veloso said, as to a different species—and most robotmakers are working hard to engineer robots that make allowances for our human feelings. At the wind farm site, I learned that “bouncing” the toothed bucket of a big excavator against the ground is a sign of inexperience in a human operator. (The resulting jolt can actually injure the person in the cab.) To a robot excavator, the bounce makes little difference. Yet Built Robotics changed its robot’s algorithms to avoid bounce, because it looks bad to human professionals, and Mortenson wants workers of all species to get along.

It’s not just people who change as robots come on line. Taylor Farms, Borman told me, is working on a new light bulb–shaped lettuce with a longer stalk. It won’t taste or feel different; that shape is just easier for a robot to cut.

Bossa Nova Robotics makes a robot that roams thousands of stores in North America, including 500 Walmarts, scanning shelves to track inventory. The firm’s engineers asked themselves how friendly and approachable their robot should look. In the end it looks like a portable air conditioner with a six-and-a-half-foot-high periscope attached—no face or eyes.

“It’s a tool,” explained Sarjoun Skaff, Bossa Nova’s co-founder and chief technology officer. He and the other engineers wanted shoppers and workers to like the machine, but not too much. Too industrial or too strange, and shoppers would flee. Too friendly, and people would chat and play with it and slow down its work. In the long run, Skaff told me, robots and people will settle on “a common set of human-robot interaction conventions” that will enable humans to know “how to interpret what the robot is doing and how to behave around it.”

But for now, robotmakers and ordinary people are feeling their way there.

Outside Tokyo, at the factory of Glory, a maker of money-handling devices, I stopped at a workstation where a nine-member team was assembling a coin-change machine. A plastic-sheathed sheet of paper displayed photos and names of three women, two men, and four robots.

ROBOTS CAN DO WELL-DEFINED TASKS,

but none has mastered humans’ ability to multitask or use

COMMON SENSE.

The gleaming white, two-armed robots, which looked a little like the offspring of a refrigerator and WALL·E, were named after currencies. As I watched the team swiftly add parts to a coin changer, a robot named Dollar needed help a couple of times—once when it couldn’t peel the backing off a sticker. A red light near its station went on, and a human quickly left his own spot on the line to fix the problem.

Dollar has cameras on its “wrists,” but it also has a head with two camera eyes. “Conceptually it is meant to be a human-shaped robot,” explained manager Toshifumi Kobayashi. “So it has a head.”

That little accommodation didn’t immediately convince the real humans, said Shota Akasaka, 32, a boyish and smiling team leader. “I was really not sure that it would be able to do human work, that it would be able to screw in a screw,” he said. “When I saw the screw go in perfectly, I realized we were at the dawn of a new era.”

IN A CONFERENCE ROOM northeast of Tokyo, I learned what it's like to work with a robot in the closest way: by wearing it.

The exoskeleton, manufactured by a Japanese firm called Cyberdyne, consisted of two connected white tubes that curved across my back, a belt at my waist, and two straps on my thighs. It felt like being strapped into a parachute or an amusement park ride. I bent at the waist to lift a 40-pound container of water, which should have hurt my lower back. Instead, a computer in the tubes used the change in position to deduce that I was lifting an object, and motors kicked in to assist me. (More advanced users would have worn electrodes so the device could read the signals their brain was sending to their muscles.)

The robot was designed to assist only my back muscles; when I squatted and put the effort into my legs, as you're supposed to, the device didn't help much. Still, when it worked, it seemed like a magic trick—I felt the weight, then I didn't.

Cyberdyne sees a large market in medical rehabilitation; it also makes a lower-limb exoskeleton that is being used to help people regain the use of their own legs. For many of its products, "another market will be for workers, so they can work longer and without risking injuries," Cyberdyne spokesman Yudai Katami said.

Sarcos Robotics, the other maker of exoskeletons, is thinking along similar lines. One purpose of his devices, said CEO Wolff, was "allowing humans to be more productive so they can keep up with the machines that enable automation."

Will we adapt to the machines more than they adapt to us? We might be asked to. Roboticists dream of machines that make life better, but companies sometimes have incentives to install robots that don't. Robots, after all, don't need paid vacations or medical insurance. Beyond that, many nations get a lot of tax revenue from labor, while encouraging automation with tax breaks and other incentives. Companies thus save money by cutting employees and adding robots.

"You get a lot of subsidies for installing equipment, especially digital equipment and robots," Acemoglu said. "So that encourages firms to go for machines rather than humans, even if machines are no better." Robots also are just more exciting than mere humans.

There is "a particular zeitgeist among many technologists and managers that humans are troublesome," Acemoglu said. There's this feeling of, "You don't need them. They make mistakes. They make demands. Let's go for automation."

AFTER NOAH READY-CAMPBELL decided to go into construction robots, his father, Scott Campbell, spent more than three hours on a car ride gently asking him if this was really such a good idea. The elder Campbell, who used to work in construction himself, now represents the town of St. Johnsbury in Vermont's general assembly. He quickly came to believe in his son's work, but his constituents worry about robots, he told me, and it's not all about economics. Perhaps it will be possible to give all our work to robots someday—even the work of religious ministry, even "sex work." But Campbell's constituents want to keep something for humanity: the work that makes humans feel valued.

"What is important about work is not what you get for it but what you become by doing it," Campbell said. "I feel like it's profoundly true. That's the most important thing about doing a job."

A century after they were first dreamed up for the stage, real robots are making life easier and safer for some people. They're also making it a bit more robot-like. For many companies, that's part of the attraction.

"Right now every construction site is different, and every operator is an artist," said Gaurav Kikani, Built Robotics' vice president for strategy, operations, and finance. Operators like the variety; employers not so much. They save time and money when they know that a task is done the same way every time and doesn't depend on an individual's decisions. Though construction sites will always need human adaptability and ingenuity for some tasks, "with robots we see an opportunity to standardize practices and create efficiencies for the tasks where robots are appropriate," Kikani said.

In the moments when someone has to decide whose preferences ought to prevail, technology itself has no answers. However far they advance, there's one task that robots won't help us solve: Deciding how, when, and where to use them. ☐

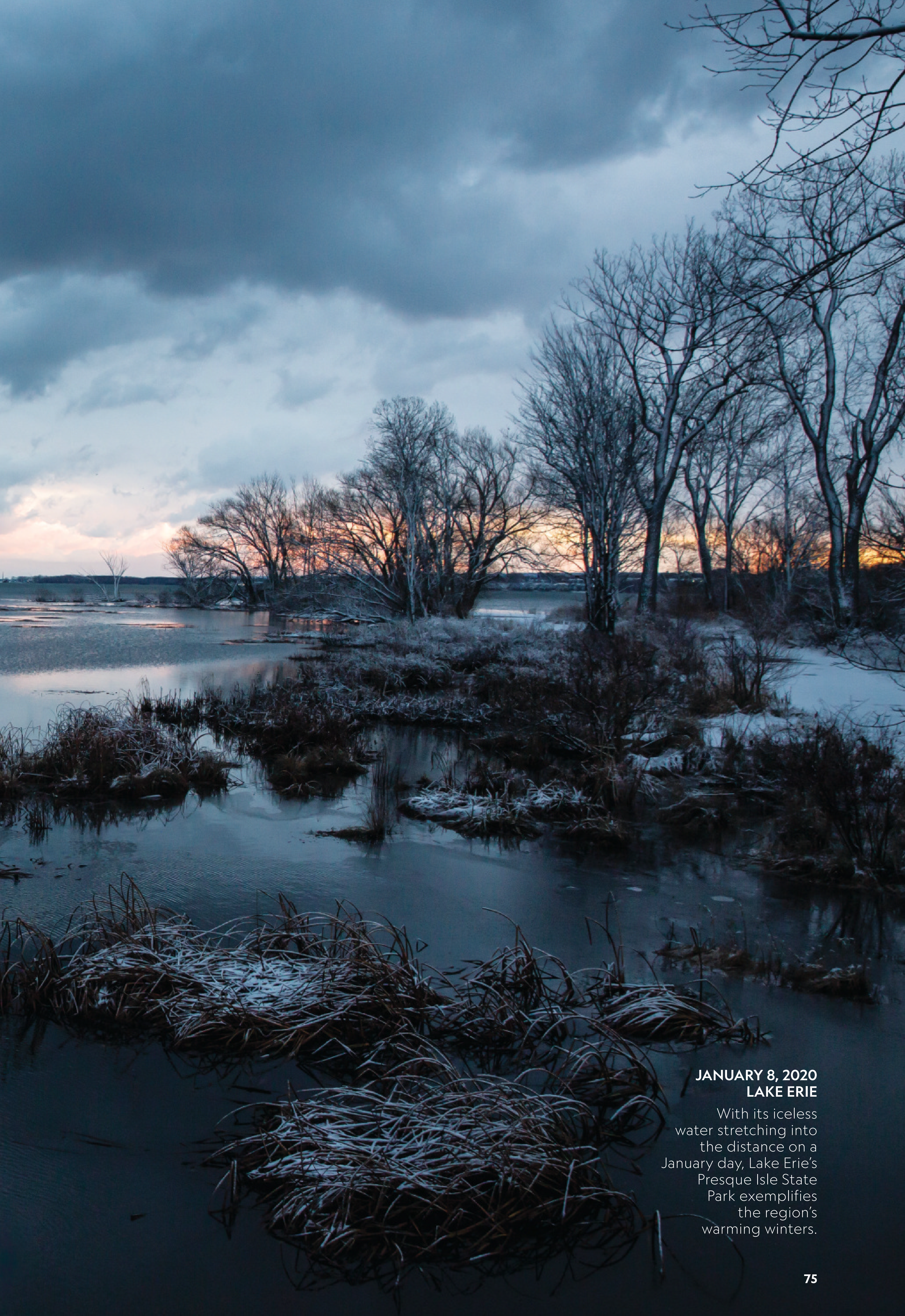
David Berreby's feature "The Things That Divide Us" appeared in the special Race Issue, April 2018. Photographer **Spencer Lowell** documented the construction of the Mars Curiosity rover for NASA.

BY **ALEJANDRA BORUNDA**

PHOTOGRAPHS BY **AMY SACKA**

A FUTURE LESS FROZEN

THE GREAT LAKES REGION'S CULTURE AND ECONOMY ARE SHAPED BY ICY WINTERS. BUT AS WARMING TURNS TRADITIONS TO SLUSH, THERE'S A GROWING SENSE OF LOSS.



JANUARY 8, 2020
LAKE ERIE

With its iceless water stretching into the distance on a January day, Lake Erie's Presque Isle State Park exemplifies the region's warming winters.

Last winter, ice covered only 19.5 percent of the Great Lakes' surfaces, nearly a record low.

FEBRUARY 8, 2020
LAKE HURON

In Oscoda, Michigan, Elena Mackenzie studies Lake Huron from one of her vacation rental cottages. Thick slabs of ice around the lake usually protect the shore from storms. But last winter was warm, and waves eroded the coastal property, causing thousands of dollars in damage.

FREEZING-DEGREE DAYS

93	64
DAYS Average 1973-2019	**DAYS** Winter 2019-2020

FOR ICE TO FORM, LAKE WATER MUST DROP BELOW 32°F—AND THE AIR MUST BE EVEN COLDER. THE AIR ABSORBS HEAT FROM THE WATER, CHILLING IT ENOUGH TO FREEZE. IT TAKES AN ACCUMULATION OF FREEZING-DEGREE DAYS (FDDs) FOR THIS TO HAPPEN. TOO FEW FDDs AND A LAKE WON'T FREEZE OR STAY FROZEN.

If the water doesn't cool enough in the winter, it will warm faster in the spring and summer.

JANUARY 7, 2020
LAKE ERIE

At a relatively shallow 210 feet at its deepest, Lake Erie cools quickly once the cold sets in. This year, though, Erie barely froze. When this couple walked their dog in a Geneva, Ohio, park, the lake had very little ice on it—and it essentially stayed that way for the rest of the winter.

FREEZING-DEGREE DAYS

58	18
DAYS Average 1973-2019	**DAYS** Winter 2019-2020

The Great Lakes' ice seasons are shortening by an average of about half a day per year.

JANUARY 26, 2020
LAKE ONTARIO

Alex Whitlock heads out to surf on Lake Ontario. Usually by this date, about 13 percent of the lake is covered in ice. But this year only 2 percent was frozen. Ontario is losing its consistent ice along the shore, and its water temperatures in the summer are creeping up.

FREEZING-DEGREE DAYS

75	61
DAYS Average 1973-2019	**DAYS** Winter 2019-2020

It's still dark and well below freezing when Kristie Leavitt pulls to a stop and turns off the ATV's rumbling motor. For a moment, there's no sound but the faint whisper of wind sweeping over the ice. The navy blue sky begins to lighten. The cold air burns in her lungs.

Bundled in a hot-pink coat that matches her fishing hut and gear, Leavitt hops down from the driver's seat onto the 18-inch-thick ice that covers this corner of Munuscong Lake, on Michigan's Upper Peninsula. Her boots crunch into a thin layer of snow as she begins the ritual of preparing for one of her favorite activities: ice fishing.

Leavitt is among the nearly two million ice anglers in the United States who look forward all year to the chill of winter. Like many others in the Great Lakes region, she also relies on the cold for a living. She helps manage her family's tourist cabins and bait shop on the edge of the lake, and the businesses make most of their money during the ice fishing and snowmobiling season.

But what Leavitt was doing that February day was a rare occurrence last winter across the Great Lakes. The long-term average for ice coverage on all five lakes—Superior, Michigan, Erie, Huron, and Ontario—is 54 percent. Last winter, ice covered only 19.5 percent of the lakes' surfaces—a near-record low.

Some lakes in the region didn't freeze at all. Others saw only faint traces of ice around their edges, or froze briefly. The weekend before Leavitt's outing, temperatures in the region shot up to 40 degrees Fahrenheit, and ice anglers slogged through slush in T-shirts.

One overly warm season isn't necessarily a harbinger of the inevitable. But increasingly, scientists can pick out patterns in the scattershot records of change from across the Great Lakes, and those patterns are pointing toward a sobering conclusion: The 2019-2020 winter, with its faint traces of ice, is likely just a taste of the future.

A history defined by the climate

THE GREAT LAKES account for about 20 percent of the freshwater on Earth's surface. For perspective: That amount could cover the entire contiguous United States in nearly 10 feet of water.

The lakes' geographical footprint is also hard to fathom. Their combined surfaces span more than 94,000 square miles, about the size of the United Kingdom. The combined measurement of the coasts of the five lakes is thousands of miles longer than either the Pacific or Atlantic coastline of the contiguous U.S.

The presence of all that water was shaped by natural changes in Earth's climate through time. But the lakes now face unprecedented change—and this time, humans are behind it.

The planet has warmed by an average of nearly two degrees Fahrenheit (one degree Celsius) since the 1880s. The Great Lakes region is on a par with this global trend: Within the basin, air temperatures have risen by an average of 1.6 degrees Fahrenheit compared with the first 60 years of the 1900s. And much of that warming has been concentrated in the winter months,

DECEMBER 28, 2019
LAKE SUPERIOR

Part of Michigan's Upper Peninsula had more freezing days than usual in 2019-2020, but there still wasn't much ice on the lake. Some areas can have normal-feeling winters even as the surrounding region does not.

FREEZING-DEGREE DAYS

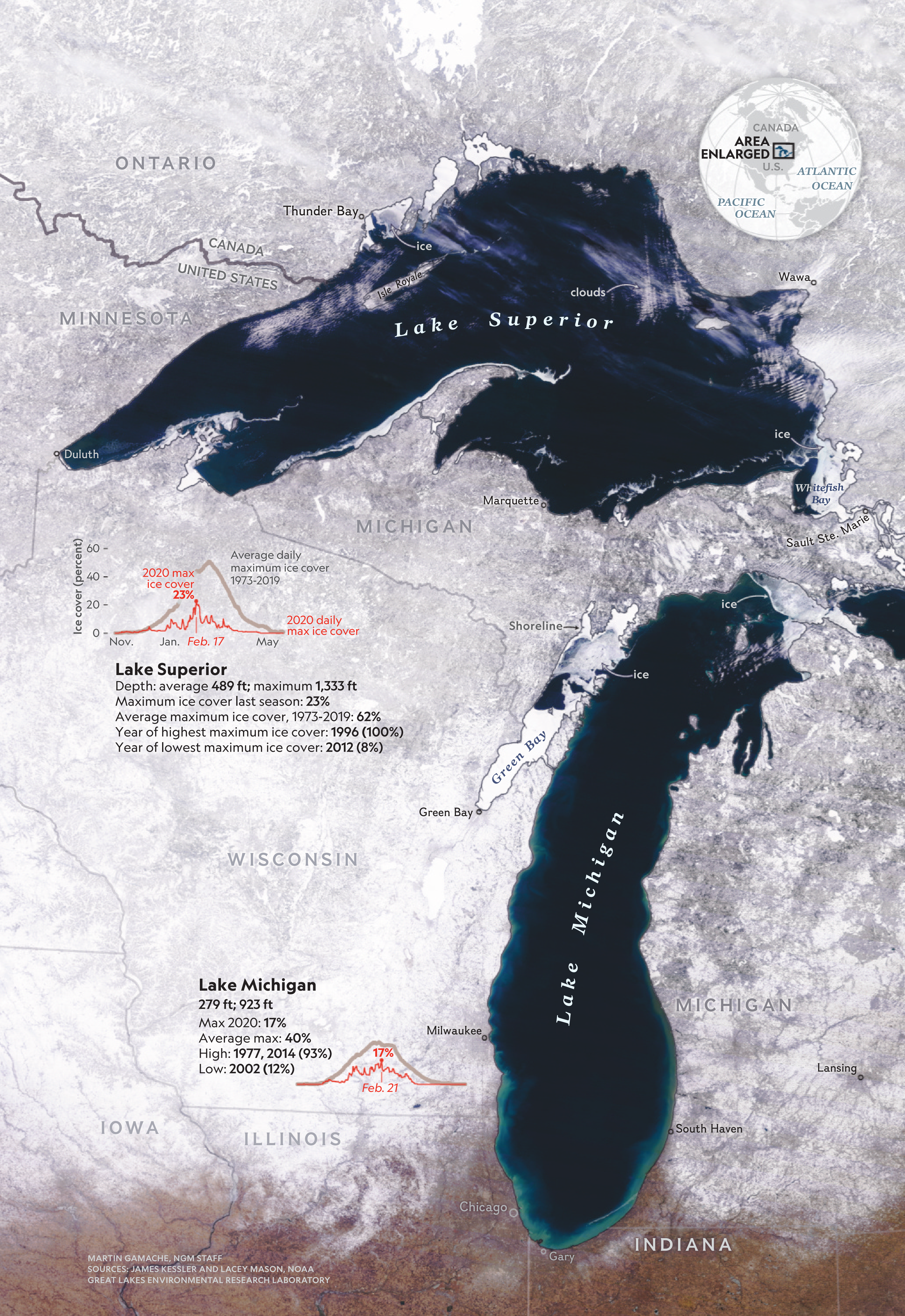
106 **DAYS** Average 1973-2019	130 **DAYS** Winter 2019-2020

JANUARY 6, 2020
LAKE ERIE

Near Cleveland, Ohio, Gracie Ezell, 13, walks along the banks of Lake Erie—in shorts. She says it's not nearly cold enough to put on long pants. Within her lifetime, warmer winters will likely be more common. Scientists predict that by 2050, the minimum temperature will stay above freezing for 21 to 25 more days a year in the Great Lakes basin.

FREEZING-DEGREE DAYS

58	18
DAYS Average 1973-2019	**DAYS** Winter 2019-2020


CANADA
AREA ENLARGED
U.S.
ATLANTIC OCEAN
PACIFIC OCEAN
ONTARIO
Thunder Bay
ice
CANADA
UNITED STATES
Isle Royale
clouds
Wawa
MINNESOTA
Lake Superior
Duluth
ice
Whitefish Bay
Marquette
MICHIGAN
Sault Ste. Marie
Ice cover (percent)
60
40
20
0
Average daily maximum ice cover 1973-2019
2020 max ice cover
23%
2020 daily max ice cover
Nov.
Jan.
Feb. 17
May
Shoreline
ice
ice
Green Bay
Green Bay
Lake Michigan
WISCONSIN
MICHIGAN
Milwaukee
17%
Feb. 21
Lansing
South Haven
IOWA
ILLINOIS
Chicago
INDIANA
Gary

Lake Superior

Depth: average **489 ft**; maximum **1,333 ft**

Maximum ice cover last season: **23%**

Average maximum ice cover, 1973-2019: **62%**

Year of highest maximum ice cover: **1996 (100%)**

Year of lowest maximum ice cover: **2012 (8%)**

Lake Michigan

279 ft; 923 ft

Max 2020: **17%**

Average max: **40%**

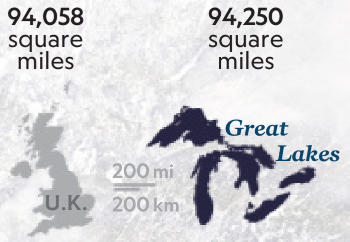
High: **1977, 2014 (93%)**

Low: **2002 (12%)**

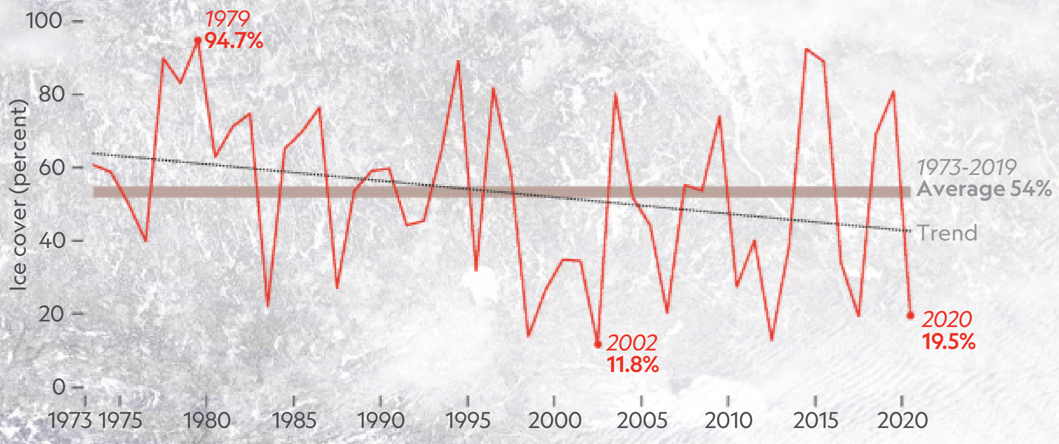
MARTIN GAMACHE, NGM STAFF
SOURCES: JAMES KESSLER AND LACEY MASON, NOAA GREAT LAKES ENVIRONMENTAL RESEARCH LABORATORY

Great Loss

Climate change has shortened the ice season considerably on the Great Lakes. A complicated combination of factors—the El Niño phenomenon, for one—influences the weather in any given year. So some winters are still cold and icy, but warmer, shorter seasons are becoming more common over the long term. In this rare, nearly cloud-free satellite image taken February 23, 2020, all five of the lakes are mostly ice free. Even the shallowest, Lake Erie, barely shows any ice.

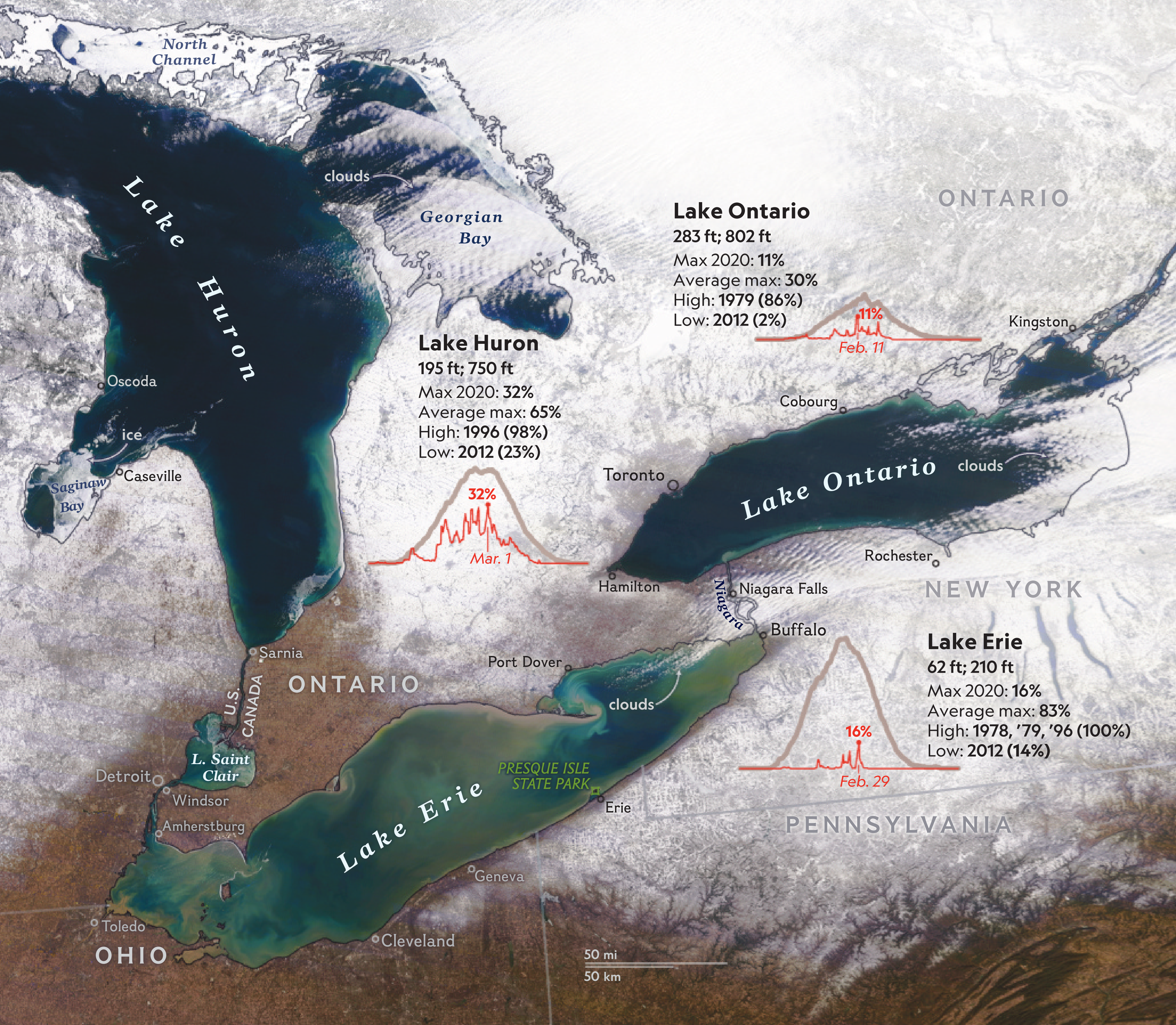

94,058 square miles
94,250 square miles
U.K.
Great Lakes
200 mi
200 km

Size comparison of the United Kingdom and the Great Lakes



ICE OVER TIME

The long-term maximum average ice cover on the lakes is 54 percent. Last winter, ice—at its maximum extent—covered just 19.5 percent of the lakes' surfaces.


North Channel
Lake Huron
clouds
Georgian Bay
ONTARIO
Oscoda
ice
Caseville
Saginaw Bay
32%
Mar. 1
11%
Feb. 11
Kingston
Cobourg
Toronto
Lake Ontario
clouds
Rochester
Hamilton
Niagara
Niagara Falls
NEW YORK
Buffalo
Sarnia
U.S.
CANADA
ONTARIO
Port Dover
clouds
16%
Feb. 29
L. Saint Clair
Detroit
Windsor
Amherstburg
PRESQUE ISLE STATE PARK
Erie
Lake Erie
PENNSYLVANIA
Geneva
Toledo
Cleveland
OHIO
50 mi
50 km

Lake Ontario
283 ft; 802 ft
Max 2020: **11%**
Average max: **30%**
High: **1979 (86%)**
Low: **2012 (2%)**

Lake Huron
195 ft; 750 ft
Max 2020: **32%**
Average max: **65%**
High: **1996 (98%)**
Low: **2012 (23%)**

Lake Erie
62 ft; 210 ft
Max 2020: **16%**
Average max: **83%**
High: **1978, '79, '96 (100%)**
Low: **2012 (14%)**

Coca-Cola

Water levels in the lakes hit record highs this year as precipitation increased.

JANUARY 9, 2020
LAKE ERIE

Calvin Knechtel of Port Dover, Ontario, stands in front of his family's restaurant near Lake Erie. Sandbags were piled up to protect the building from flooding. After this photo was taken, the lake broke its February high-water record, set in 1987.

FREEZING-DEGREE DAYS

70	58
DAYS Average 1973-2019	**DAYS** Winter 2019-2020

nudging the ice ever closer to its tipping point.

“Lake ice is an amazing indicator of climate,” says Sapna Sharma, a lake ecologist at York University in Toronto. It’s “a clear indication of climate change—and people have recorded it, in some cases, for centuries.”

In Japan, priests at a Shinto temple have kept an almost 600-year record of when their lake freezes all the way across. Natural climate cycles emerge from that record—dwarfed in recent decades by the human-caused warming that has gripped the planet. Merchants who used Finland’s Tornio River for trade tracked the date the ice broke up each year from 1693 onward.

In Lake Superior, shipping companies have kept records of ice formation and breakup since 1857. The records show cold years with long stretches of early ice, warm years with less. But overall they are a clear signal of human-caused warming since the industrial revolution.

“What’s happening in the Great Lakes region is a small part of a bigger story,” says Lesley Knoll. A lake expert at the University of Minnesota’s Itasca Biological Station, she studies people’s cultural relationships with frozen lakes.

A threat to idyllic winter rituals

FOR LEAVITT, 38, the ice has always been a place to bring her life into focus.

When her family would drive from downstate Michigan to visit her grandparents, who owned the lakeside camp at the time, Leavitt would layer on warm clothes, collect a cooler of minnows from the bait shop, and walk out onto the ice as far as she could. She’d crank her hand-powered auger, cut a channel through the thick ice, and open a portal to the quiet underwater world.

The old-timer at the bait shop had handed her a rod—a scant three feet long, designed for ice fishing—off the wall the first time she’d gone in there. He showed her how to tie a lure, and how to tip the rod up and down to make the lure and minnow glitter in the water’s depths. That first rod hangs on the wall of her shanty to this day.

Back then, when she was just a kid, it was a simple affair. She’d bring what little equipment she had out to the ice, perch on an overturned five-gallon bucket, and sit there for hours, tipping the nose of the rod up and down like a conductor’s baton, calling to the symphony of fish below. She didn’t catch much. But the feel of it—the clouds skidding overhead, the water changing colors below her feet, the wind swishing past—got locked into her brain as the essence of winter.

Leavitt isn’t alone. Ice provides crucial things to everyone who goes out on it. Respite for some, dearly held recreation for others, food, and much more. Snow and ice also are critical components of local U.S. economies across the region: Winter skiing and snowmobiling account for some $3.5 billion, a recent estimate said. A single ice fishing tournament can inject hundreds of thousands of dollars into communities.

But in parts of Lake Superior, the ice season has been shrinking by an average of almost a day each year for the past few decades. That means the year Leavitt was born, a winter on Superior would have included more than a month more ice cover than it does today. Superior also is warming faster than every other large lake on Earth, except Lake Fräcksjön in Sweden.

The other Great Lakes’ ice seasons are shrinking as well, by an average of about half a day per year. That may sound small and benign, but it masks much more critical change in a place where the line between ice and no ice, snow and rain, can be razor thin.

LEFT AND BELOW

JANUARY 10, 2020
LAKE ERIE

From left: Kirk Williams, Cole Williams, Lee Spitzke, and Mel Lyall hunt ducks near Amherstburg, Ontario. They had hoped to make the seasonal switch from hunting to snowmobiling, but it didn't get cold enough. "Everybody used to snowmobile here," Kirk Williams says. "We used to have a lot of snow. But now it's here for only a short period of time. Winters are gone."

FREEZING-DEGREE DAYS

68	47
DAYS Average 1973-2019	**DAYS** Winter 2019-2020

In the most dire warming scenarios, more than 200,000 lakes in the Northern Hemisphere could have more ice-free years.

JANUARY 29, 2020
LAKE ONTARIO

Ice fishing has been the norm in winter, but these anglers need boats on the Niagara River, which flows into Lake Ontario. Waters are warming faster than the air, and air temperatures have risen at least 1.6 degrees Fahrenheit since 1900.

FREEZING-DEGREE DAYS

70	58
DAYS Average 1973-2019	**DAYS** Winter 2019-2020

OMPANY

Winter recreation feeds millions of dollars into the local economies along the lakes' shores.

FEBRUARY 15, 2020
LAKE HURON

In Caseville, Michigan, a participant in the polar bear plunge braves the icy Lake Huron waters during the town's 28th annual Shanty Days festival. The event once took place on the ice. Now most activities are on the shore because the lake ice is not reliably thick enough.

FREEZING-DEGREE DAYS

93	64
DAYS Average 1973-2019	**DAYS** Winter 2019-2020

MARCH 1, 2020
LAKE MICHIGAN

A woman and her dog walk the muddy beach along unfrozen Lake Michigan, where the 2019-2020 winter ice cover never topped 20 percent.

FREEZING-DEGREE DAYS

80 **DAYS** Average 1973-2019	53 **DAYS** Winter 2019-2020

It's difficult to see the change clearly, in some cases, because there's huge year-to-year variation, says Jia Wang, a climatologist at NOAA who focuses on ice cover in the Great Lakes region. Though they're hundreds of miles from the oceans, the lakes feel weather influences from both the Pacific and the Atlantic, and incorporate those weather patterns into their own.

So, although one year may be warmer than the one before, some recent winters were icy cold. In 2013-14, the polar vortex carried frigid air from the Arctic into the continental U.S., and the cold stretched well south of the Great Lakes. Total ice cover on the Great Lakes spanned more than 90 percent, growing so thick in some places that the augers ice anglers used couldn't reach the water.

The extra-tricky part is that the presence and growth of lake ice each winter create a complicated sequence of events.

Maybe it gets cold enough for ice to form early in the winter—but if a stretch of bitter wind keeps the water's surface churning, ice will form later. Maybe the summer before was extra warm, zapping enough extra heat into the water that it takes it extra long to cool off and get to the point when it can start to freeze. Maybe a bunch of snow falls early in the season, insulating the ice from the top and, counterintuitively, keeping it from growing quickly through the cold temperatures.

Some factors aren't so complicated. The air is getting warmer. So is the water, in many places faster than the air. In the Northern Hemisphere, nearly 15,000 lakes that used to freeze consistently now ice over intermittently, if at all.

'It feels like something's wrong'

WINTER IS INTEGRAL TO the culture of the Great Lakes region. Warm mid-February days draw Michiganders outside, but they're uneasy.

"We like it when it's nice like this, but it's not real winter unless it's, like, minus 40," says Kasey Spencer, a lifelong Upper Peninsula resident. "When it's cold, we're miserable—but we're also really happy, you know? If we have a really warm winter, it feels like something's wrong."

What the future holds is both more and less. There's more heat in the air, trapped by the greenhouse gases humans continue to pump into the atmosphere. Climate experts forecast air temperatures in the Great Lakes basin to rise by another degree or so by 2045, and roughly six to 10 degrees by 2100. There's also more heat in the water, forced in during long, hot summers.

However, some scientists predict that by the end of the 2030s, there will be 15 to 16 fewer days with the minimum temperature below freezing in the Great Lakes basin, and by the 2050s a few more. By the end of the century, depending on the strength and aggressiveness of climate actions taken, 27 to 42 fewer days each year could be below freezing, scientists say.

In the 2015 Paris climate accord, 195 signatories agreed to try to limit planetary warming from surpassing 3.6 degrees Fahrenheit (two degrees Celsius) beyond preindustrial levels. Sharma estimates that even if those goals are met, more than 35,000 Northern Hemisphere lakes could lose their consistent winter ice. Under the most dire warming scenarios, more than 200,000 lakes could have more ice-free years.

"Things like ice and water have a long memory," says Richard Rood, of the University of Michigan, who studies the ways climate change is playing out across the Great Lakes region. "What we're seeing is some systematic increases in temperature over the long run, putting you closer to the freeze-thaw cycle of water. And you're seeing winters getting warmer, shorter—so you just don't have the amount of time you used to for thermodynamics to do their thing."

If the water doesn't cool down enough during the winter, it gets warmer, faster, in the spring and summer. Over time, and especially as the climate keeps up its inexorable warming, the system could wind itself up more and more—a self-reinforcing loop.

"At some point these areas that maybe sometimes get ice and sometimes don't, they're going to transition to never getting ice," Knoll says. "How are people going to interact with those water bodies when they never get ice at all? How are they going to adjust? How are their lives going to change?"

Leavitt hesitates when she starts to talk about the future. The world as she sees it is still ice covered; each year is another opportunity for cold. But occasionally, the concerns bubble up. "Sometimes I just don't know," she says as she sets up to fish, strands of hair wisping around her intent face. "Will all this still be around when I'm 70?" ☐

Staff writer **Alejandra Borunda** covers the environment. **Amy Sacka** is a documentary photographer based in Detroit who focuses on the people, culture, and environments of the Great Lakes.

BY **RICHARD CONNIFF**
PHOTOGRAPHS BY **KLAUS NIGGE**

Nobody's Fool

FORGET THE DIM-WITTED STEREOTYPE: THE OSTRICH IS A **SHREWD SURVIVOR** IN A WORLD OF **PREDATORS.**

Standing tall at the southern tip of Africa, a male ostrich surveys the shore near the Cape of Good Hope. Growing up to nine feet tall and 300 pounds, Earth's biggest bird has no shortage of gangly, comic appeal—but this bird is no easy mark for its enemies.

Three female ostriches (brown feathers), three males (black feathers), and 42 chicks keep watch for jackals and other predators in Tanzania's Tarangire National Park. Chicks hatched in communal nests may stay together as long as a year or two.

Most of us happily get by on a single cartoonish idea about ostriches: They're the big birds that bury their heads in the sand in times of crisis, supposedly thinking that if they can't see danger, danger can't see them.

In our ragbag of stereotypes, ostriches have thus become the quintessential dim-witted animals. Even the Bible says they're dumb, and bad parents too.

The head-in-sand idea is a threadbare, 2,000-year-old hand-me-down from the Roman naturalist Pliny, who sometimes passed on tall tales. Think about it. Ostriches have long, bony legs, a torso held aloft like a great floating raft of flesh and feathers, and a neck like a periscope, topped by a wedge-shaped head with eyes bigger than an elephant's, at a height of up to nine feet. It is an unlikely design for head-burying.

Ostriches do in fact often hold their heads low to the ground—not under it—to feed on plants or to tend their nests. But their necks are light and flexible, with 17 cervical vertebrae to our seven, and easily move up and down, side to side, and front to back. And their giant eyes help them keep close watch on the world around them.

They have reason to stay alert. For starters,

The world's fastest animal on two legs, ostriches have been clocked sprinting at more than 40 miles an hour, and they can run long distances at about 30 miles an hour. The secret of their speed? Massive thigh muscles, long lean legs, elastic tendons, and an extra-large claw on each foot for traction.

they're basically oversize chickens in habitats populated by hungry lions, leopards, hyenas, African wild dogs, and cheetahs. And while adult ostriches are too formidable to be easy prey—their kick can break bones, and the larger of their two claws can disembowel an adversary—they're much better at fleeing than fighting, with a top escape speed of more than 40 miles an hour.

Ostriches are basically oversize chickens in areas populated by hungry lions, leopards, hyenas, and cheetahs. But their kick can break bones, and they can run faster than 40 miles an hour.

What also keeps them alert is the peril facing their offspring. Ostriches make their nests—just clearings on the ground—in the open, where their eggs can be smashed to bits by any blundering elephant, never mind hungry predators. (Well, mind the predators too.) Success requires improbable luck. The largest bird on Earth, and one of the most conspicuous, must keep its nest undetected—or stand ready to defend it—for more than two months, from laying the first eggs to hatching. Failure is routine, and that is the driving force behind its ingeniously communal nesting behavior.

A good place to see ostriches is Tarangire National Park in northern Tanzania. It's 1,100 square miles of dry hills and grassy plains along the Tarangire River. The elephants spread out in great herds here, together with zebras and wildebeests by the thousands. Ostriches are common too, but when I join University of Dar es Salaam wildlife ecologist Flora John Magige, an expert on ostrich behavior, on a search for nests, our first discovery is a bust.

Nine eggs are scattered in the brush over an area roughly 75 feet across. Magige surveys the area like a detective working a murder scene. She points out a faint scraping in the dirt where the nest had been, and right next to it the freshly dug burrow of an aardvark. Not guilty, she thinks. The scattering is more likely the work of a hungry predator, but not a big one, because all the eggs are still intact. Maybe a jackal then? In any case, the male and female ostrich have moved on, as they often do when a nest is disturbed. It's possible that they'll nest together again.

But ostriches in breeding season are relentlessly promiscuous, with both males and females seeking liaisons with multiple partners. No doubt they have their reasons. But from an evolutionary perspective, playing the field is a way to get diverse DNA into as many nests as possible and compensate for the fact that most nests fail.

Thus at 10:30 one morning we spot a couple mating about 500 yards off the park's main road. They break apart, and as the male walks on, his most recent consort and two other females follow. One of them soon begins soliciting him, holding her wings away from her body and shaking them like pom-poms. In breeding season, females can produce an egg every two days, and the urge to make the egg fertile is insistent. But males are often in short supply, perhaps because they jealously guard their territory, forcing some to emigrate.

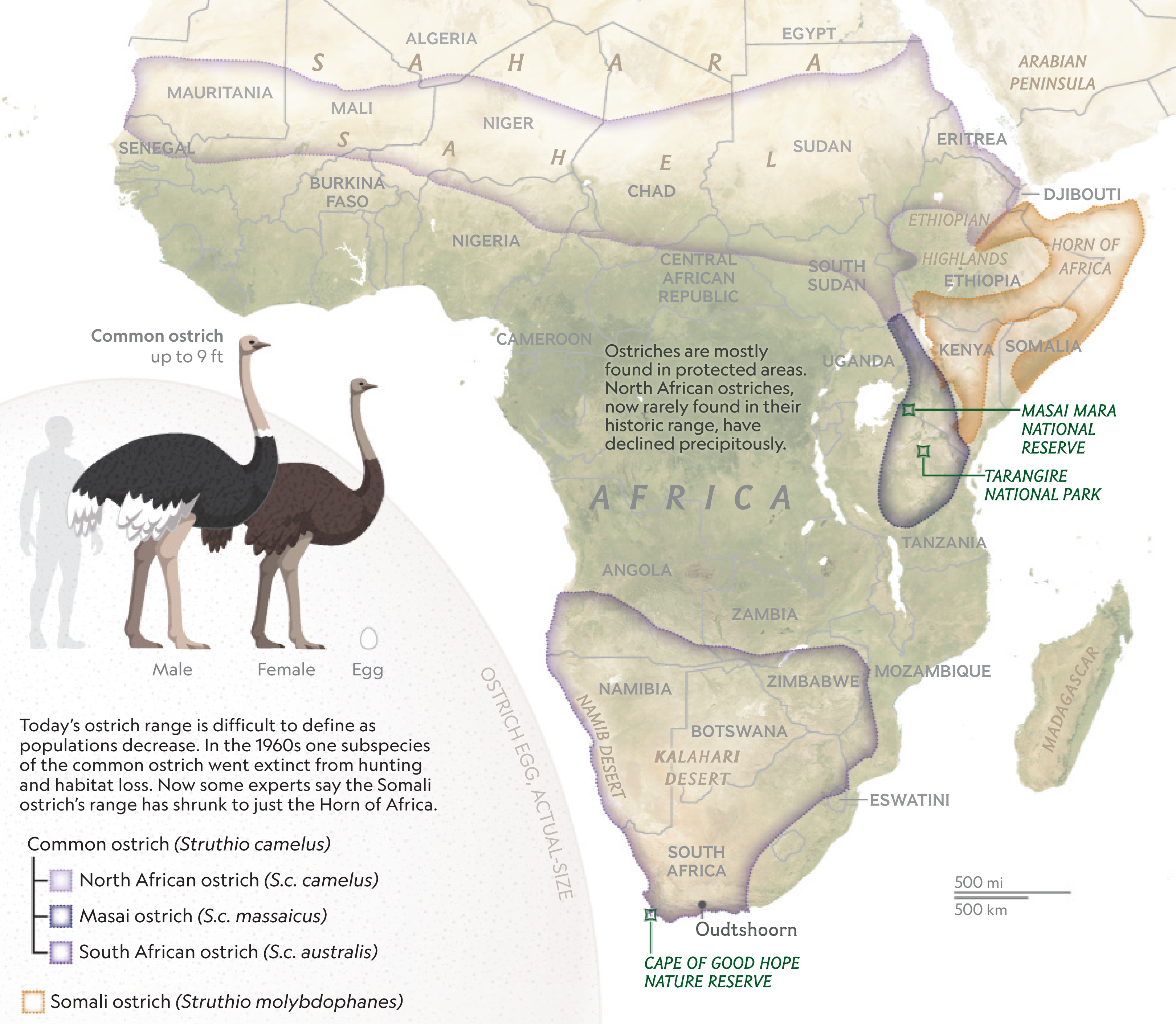
The male ignores her. Their walk takes them on a meandering route past tall, spreading acacia trees and squat baobabs with fat trunks scarred by the endless scraping of elephants. By the road, the female tries again, her wings shimmying. A safari vehicle shoots past, casting a train of dust across her romantic display. The male walks on. Undaunted, she finds an excuse to walk in front of him, wings low and trembling.

"But he isn't convinced," Magige says.

The seduction takes more than an hour. They find their way down to a sandy beach on the Tarangire River. As she walks away, he drops to the ground, finally smitten. Then he executes the full pre-copulatory display, like a head-banging air guitar player: wings spiraling, body rocking wildly from side to side, head flung back so far it bounces off his ribs, *ka-thump* on one side, *ka-thump* on the other.

She strolls on, indifferent now. Finally, though, they get together in the dry riverbed. He writhes over her for a minute or two as she sits sphinxlike, dignified, head straight in the air. At his moment of greatest ecstasy, she spots something tasty on the sand and reaches out to eat it.

Afterward everyone drinks and feeds for a while along the river, a sort of ostrich picnic. We turn to leave for our own lunch, and when we pause for one last look back, all three females


Common ostrich
up to 9 ft
Male
Female
Egg
OSTRICH EGG, ACTUAL-SIZE
ALGERIA
EGYPT
ARABIAN PENINSULA
S A H A R A
MAURITANIA
MALI
NIGER
SENEGAL
S A H E L
SUDAN
ERITREA
BURKINA FASO
CHAD
DJIBOUTI
ETHIOPIAN HIGHLANDS
ETHIOPIA
HORN OF AFRICA
NIGERIA
CENTRAL AFRICAN REPUBLIC
SOUTH SUDAN
CAMEROON
UGANDA
KENYA
SOMALIA
MASAI MARA NATIONAL RESERVE
TARANGIRE NATIONAL PARK
A F R I C A
TANZANIA
ANGOLA
ZAMBIA
NAMIBIA
ZIMBABWE
MOZAMBIQUE
MADAGASCAR
NAMIB DESERT
BOTSWANA
KALAHARI DESERT
ESWATINI
SOUTH AFRICA
Oudtshoorn
CAPE OF GOOD HOPE NATURE RESERVE
500 mi
500 km

Ostriches are mostly found in protected areas. North African ostriches, now rarely found in their historic range, have declined precipitously.

Today's ostrich range is difficult to define as populations decrease. In the 1960s one subspecies of the common ostrich went extinct from hunting and habitat loss. Now some experts say the Somali ostrich's range has shrunk to just the Horn of Africa.

Common ostrich *(Struthio camelus)*
- 🟪 North African ostrich *(S.c. camelus)*
- 🟪 Masai ostrich *(S.c. massaicus)*
- 🟪 South African ostrich *(S.c. australis)*

🟧 Somali ostrich *(Struthio molybdophanes)*

are approaching the male, their wings held out and softly shaking.

WE HAD FOLLOWED this group of ostriches in the hope that they would lead us to a nest, but an ostrich nest can be hard to see even when you know exactly where it is. The male typically tends it by night, sitting with head up, on the lookout. The female takes over by day. When she slants her tail feathers down in back, and her long neck in front, she can look like nothing more than an old termite mound or a tree stump. Sometimes the easiest way to find a nest is just to sit and wait for another ostrich to come visiting, which happens with surprising frequency.

One afternoon we take up position in a great open plain and soon find that it's a thriving ostrich territory. Somewhere out in front of us a female is sitting on her nest. The nesting male is grazing a few hundred yards to the left and not seeming to pay much attention. But when another male turns up a half mile or more in the distance, he begins walking toward him in a determined way, then running. As in humans, promiscuity and possessiveness can coexist: The nesting male aims to monopolize his partner's matings, and that means running off rival males.

What's more surprising is how the nesting pair responds to visiting females. Other species have evolved elaborate defenses to deter "brood parasites," birds that try to fob off the tedious work of parenting by slipping their eggs into other birds' nests. Ostriches are different. When another female approaches, the nesting female will often stand up and step aside, allowing the visitor to lay eggs alongside her own. According to some studies, the nesting female is typically the biological mother of only about half the 19 or 20 eggs she can successfully incubate, with minor females contributing the rest. It's not brood parasitism; it's communal nesting, and like promiscuity, it's a way for ostriches to achieve reproductive success in a hazardous world.

That's not to say all is sisterly love and

CHRISTINA SHINTANI AND TAYLOR MAGGIACOMO, NGM STAFF. SOURCES: IUCN; BRIAN BERTRAM; FLORA JOHN MAGIGE, UNIVERSITY OF DAR ES SALAAM

LEFT TO RIGHT, FROM TOP

It's ostrich breeding season in Tarangire National Park. A male's red, swollen neck and legs announce that he's on the hunt for mates.

After performing an impressive courtship dance in which he waves his wings and flaunts his feathered finery, the male mounts a hen. Unlike most birds, male ostriches possess a penis and inseminate females internally.

The female lays her eggs on the ground. Other hens may lay eggs alongside hers—a strategy known as communal nesting—but only the primary hen and her mate will guard and incubate the eggs.

Eggs hatch after 42 days' incubation, but only about 10 percent of nests are successful. Chicks that survive strike out on their own after a year or two.

happiness. The nesting female may not have much choice, according to Brian Bertram, the biologist who provided the first detailed description of communal nesting, in 1979. Resisting a visiting female could lead to conflict and attract lions and other predators. It could also break eggs, mostly her own, and the smell could draw hyenas or jackals. Besides, the visiting female typically towers above the resident female. Bertram observed one nesting female inclined to stay seated. So the visitor just stood there pecking at her head "fairly gently" but persistently for 20 minutes, until finally the nesting bird stood up, exasperated, and stepped aside.

Communal nesting provides the nesting couple with certain selfish benefits, Bertram says. For the male, his philandering in the neighborhood means that he has probably fathered about one-third of the eggs added to the nest by nearby females. For the nesting female, having extra eggs in the nest dilutes the risk. No one knows how she can tell the difference, but she routinely keeps her own eggs in the center of the nest, and consigns those of other females to what Bertram calls "the doomed outer ring." Having more chicks together after hatching also makes it less likely her chicks will be the ones picked off by a predator.

ONE OF THE MOST striking things to me about ostriches, apart from their size, is the sense that they are in motion even when standing still.

Spotted hyenas in Kenya's Masai Mara National Reserve feast on an ostrich egg. The world's largest bird lays the world's biggest egg—as big as a ripe cantaloupe and equivalent to two dozen chicken eggs. To crack open the strong shells, predators get inventive. Jackals sometimes bowl one egg against another; Egyptian vultures toss stones.

CHRISTINE AND MICHEL DENIS-HUOT, NATURE PICTURE LIBRARY

This is especially true of the female, because her tawny coloration makes the fluttering of her feathers more visible. The male's black-and-white plumage can seem more constrained, like a tuxedo. In both sexes, the feathers are unusually long and full, especially on the wings and tail. They also lack the tiny hooks, or barbicels, that cinch feathers together in most other birds. This is what gives them such a captivating tendency to drift and billow in the breeze. It's functional: The ostrich can loosen the feathers to help dissipate body heat or draw them close to conserve it. That flounciness is also the quality that has caused human fashion to repeatedly fall in and out of love with ostrich feathers.

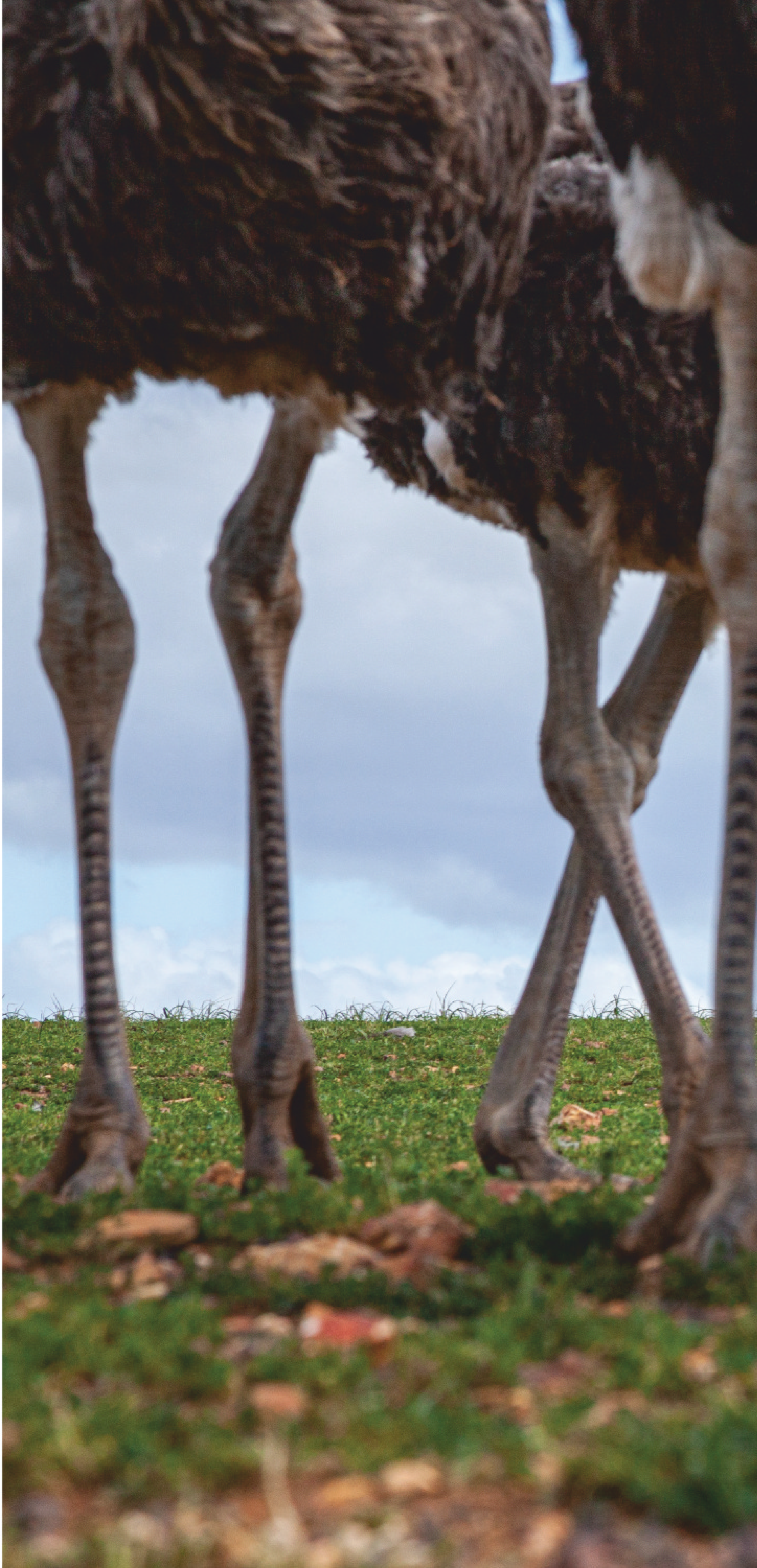
The route to the heart of the ostrich trade runs through a narrow, red-rock pass in the Swartberg mountains of South Africa's Western Cape Province. Below that natural cleft, quilted farm fields spread out across a semiarid plateau encircled by ragged mountains. The Little Karoo is an oddly remote and isolated source for the feathery excesses of Ascot racegoers and Las Vegas showgirls. But the region around the town of Oudtshoorn (pronounced OATS-horn) has been the center of the world ostrich trade for more than 150 years.

Beginning in the 1860s, when the feather trade was already pushing ostriches to extinction in some areas, farmers here helped pioneer captive breeding. The communal nature of ostriches may have made these birds more amenable to life in captivity. Their inability to fly or jump also helped. Fields (or "camps") enclosed by chest-high wire fences now contain thousands of ostriches in seeming harmony, sometimes spread out like feathered chess pieces, sometimes seated in clusters. The ostrich's evolution suited it to the desertlike vegetation of the Little Karoo, which also proved ideal for growing bright green patches of irrigated alfalfa, the preferred feed for farmed ostriches.

Farmworkers wander through the camps each day during the breeding season, gathering eggs for delivery to commercial incubator units: 112 eggs per rack, 1,008 eggs per unit, slowly rotating, at 96.8 degrees. "At day 42," says Saag Jonker, a prominent local farmer, "the chick breaks through into an air pocket in the egg, inhales, and gets the strength to break through the shell." It may live a year, if bred for meat and leather, up to 15 years if bred for feathers, with plucking at roughly nine-month intervals.

The ostrich trade has always been an unpredictable business, with prices fluctuating wildly at the whim of international fashion. It's in a down cycle at the moment, and Jonker and his wife, Hazel, chat hopefully about Kate Middleton's taste in ostrich-feather hats and about how soon Louis Vuitton might come back to ostrich leather for its bags.

The golden age for the ostrich trade and Oudtshoorn began in about 1870, driven by demand for ostrich feathers on the hats of fashionable women. "Feather mansions" from that era still grace Oudtshoorn's streets with towers, gables, wraparound porches, and fancy trimwork known locally as "broekie" lace, from the Afrikaans word for women's underwear. It's a



Ostriches are the only animals with double kneecaps, a little-understood oddity that may help them run faster. But speed isn't the only asset that enables such large, conspicuous birds to escape the perils of the African savanna. They're also equipped with the largest eyes of any land animal and vision so sharp that an ostrich on an open plain can spot trouble almost two miles away.

RICHARD DU TOIT, NATURE PICTURE LIBRARY

measure of just how prosperous the trade was that in 1912, the most valuable cargo carried by the *Titanic* wasn't diamonds or gold but 12 cases of ostrich plumes valued at $2.3 million in today's money. That all ended, though, in 1914, when war and open-roofed motorcars made big, plumy hats suddenly unfashionable.

One morning in town, I run into Maurice "Mickey" Fisch, a retired ostrich farmer and a remnant of the Jewish community that once dominated the world ostrich trade from Oudtshoorn. Jewish immigrants, driven from Europe by political and economic oppression, began arriving in the late 19th century.

"And the Afrikaners welcomed them with open arms," Fisch says. "They accommodated them in their homes, sometimes for days."

Early immigrants tended to become peddlers. But those who followed had worked often in commodities or the clothing trade, and the diaspora meant they had connections with immigrant communities in those trades in London, New York, and other great cities. Oudtshoorn's feather business grew up largely through those connections, in a network that extended from the Yiddish-speaking feather buyer traveling farm to farm, on up to the artisans who fabricated ostrich-feather products and the retail merchants who sold them. At the height of the trade, several hundred Jewish families lived in Oudtshoorn and supported two synagogues.

Fisch holds open a book about local history

At an ostrich farm in Germany, a chick takes shelter between a parent's massive feet. In the 18th century ostrich feathers became so fashionable in Europe that intense hunting caused the birds to decline over much of their range. Domesticated in South Africa in the 1860s, they're now raised worldwide for their feathers, meat, and supple leather.

and points to a photo of his grandfather and namesake, Maurice Lipschitz. "He was the biggest ostrich farmer in the world," says Fisch. "When he died in 1936, he owned 35 farms." Montague House, the feather mansion he built, had a ballroom, a wine cellar, and a 400-gallon tub lined with Carrara marble. This may not have been as elegant as it sounds: There were six sons and four daughters, says Fisch, and "one bath a week for all those children."

The house still stands, but it's subdivided now into a restaurant, a shop, a residence, and a doctor's office. The ostrich trade is in the hands of a nondenominational co-op, and the Jewish families have dwindled to so few that the surviving synagogue has to bring in Jewish worshippers from the surrounding area to make a minyan, a quorum, for holy day services. After 50 years of farming, Fisch too has left the ostrich business, and says good riddance. His view of ostriches echoes Job 39:16-17, which calls them "deprived" of wisdom and indifferent even to the well-being of their own offspring. Ostriches, says Fisch, are "stupid birds that just had nice feathers."

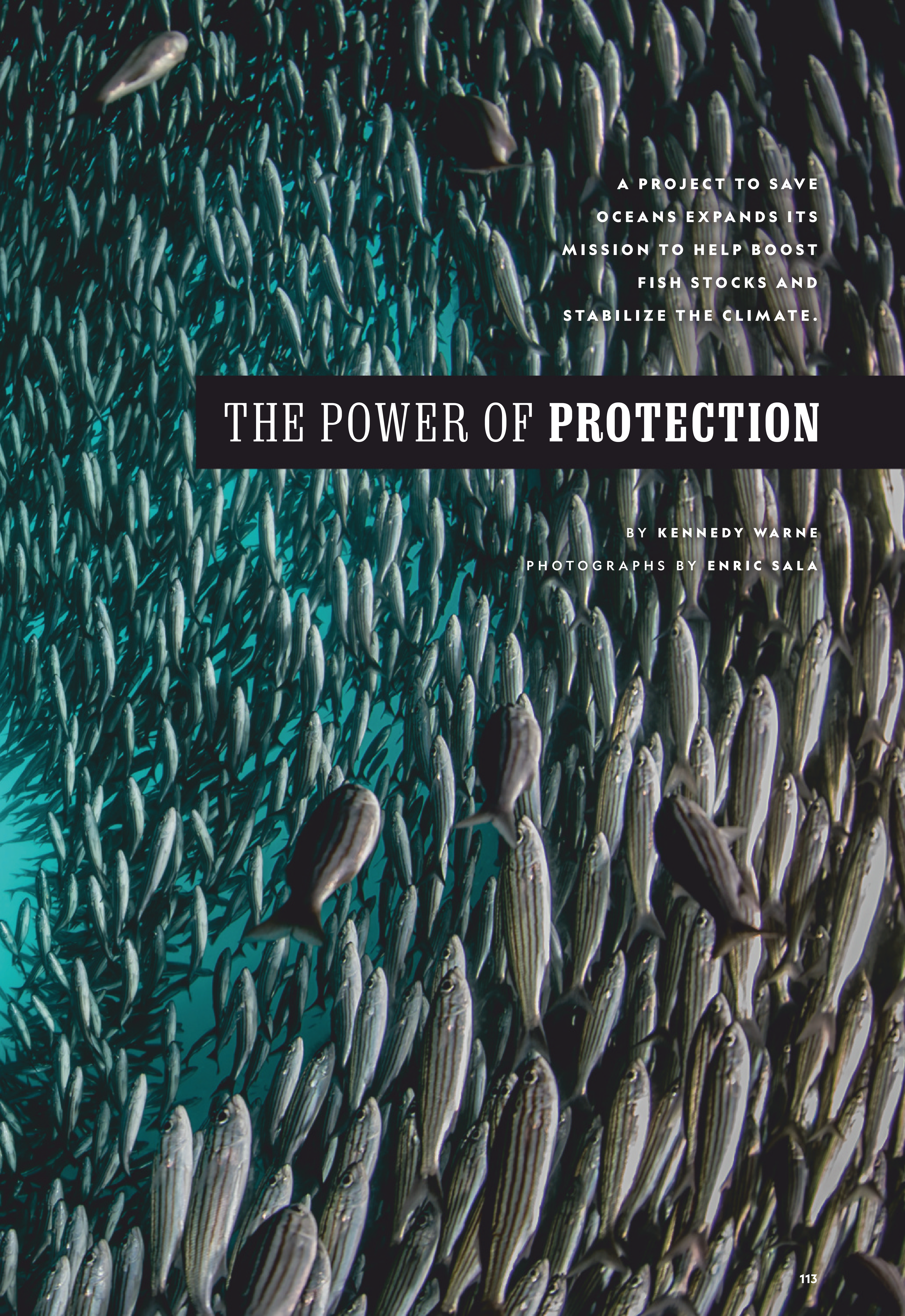
I don't ask him about their parenting skills, but I get a chance to find out for myself soon after. One morning at De Hoop Nature Reserve on the southern tip of Africa, I watch a male ostrich and a female feeding. They are watching me too, but after a while they relax, and, as if on signal, nine ostrich chicks come out of hiding. They're plump little creatures a week or two old, dodo-like, with tawny, mottled necks and short, bristling down on their bodies. They feed, and their parents follow close behind, also feeding.

Soon after, a murderous trio of baboons approaches across a field. The male ostrich glowers, then runs forward, pushing them away. The baboons come back again and again, but each time the male blocks their path. Then an entire troop of baboons wanders out onto the clearing. The chicks huddle together nervously as the two adult ostriches stand glaring at these intruders. Prudently, the baboons pass by, looking elsewhere, as if an ostrich sandwich is the last thing on their minds.

The baboons have no sooner moved off than it begins to rain, a lashing, sideways, coastal sort of cloudburst. The male and female immediately sit down and lift their wings as the chicks come racing in for cover. So many of them nose in under the dad's left wing that they look like piglets on a sow. Then the wings come down and they vanish, entirely sheltered from the chilling rain. When the downpour finally stops, one of the chicks pops up its head through the wing feathers and looks around, literally wearing its parent as a raincoat. It's pretty much the opposite of burying its head in the sand. The weather being acceptable, it slips out, still dry and warm, into the world again.

Maybe you wouldn't call that intelligence, but it suggests a certain genius for survival. And I walk away thinking we should all be such good parents. ☐

Author **Richard Conniff**'s books about wildlife include *Swimming with Piranhas at Feeding Time.* **Klaus Nigge** trained and worked as a biologist before becoming a wildlife photojournalist.



A PROJECT TO SAVE OCEANS EXPANDS ITS MISSION TO HELP BOOST FISH STOCKS AND STABILIZE THE CLIMATE.

THE POWER OF **PROTECTION**

BY **KENNEDY WARNE**

PHOTOGRAPHS BY **ENRIC SALA**

Beneath the surface of a stormy sea off Palau lie diverse, thriving corals. The tiny island nation has protected 80 percent of its waters as a no-take zone closed to fishing—the largest percentage of protected marine territory in the world. The remaining 20 percent can be fished only by Palauans.

PREVIOUS PHOTO

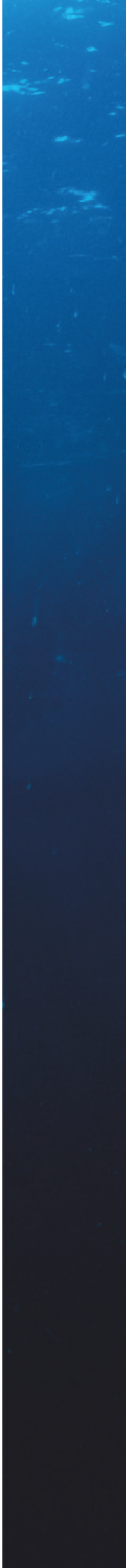
Black-striped salema off Isabela Island in the Galápagos make way for a sea lion. After a 2015 Pristine Seas expedition, a new reserve around Darwin and Wolf Islands added more than 15,000 square miles of protected area that is closed to fishing.

When Enric Sala quit his job as a professor at Scripps Institution of Oceanography in 2007, it was because he was tired of writing death notices. 'I found myself writing the obituary of the ocean with more and more precision,' he says.

Rather than spend any more of his life documenting the dying, Sala decided to try to safeguard the living in the few remaining patches of ocean where the Grim Reaper had yet to swing his scythe.

These scattered remnants are the last wild places of the sea—the marine equivalent of the remotest tracts of old-growth forest in the Amazon—still undamaged by overfishing, pollution, and climate change. "It was necessary for us to go to places that still look like the ocean as it was 500 years ago," Sala says. "To go back to the best baselines we have for what a healthy ocean used to be like. These places are the blueprint. They are the instruction manual. Maybe we cannot bring all of the ocean back to this state, but these places show us what the potential is. They give us hope."

To protect these places, Sala and the National Geographic Society launched the Pristine Seas project in 2008. Over the past 12 years, Pristine Seas has helped create 22 marine reserves, from the giant kelp forests south of Cape Horn to the humpback whale nurseries of Gabon. These make up two-thirds of the world's fully protected



A school of juvenile jacks near Gabon shelters amid the six-foot tentacles of a jellyfish. The Gabon Marine Protected Area Network covers 28 percent of Gabon's waters and includes two dozen species of whales, dolphins, and turtles.

marine areas—covering more than two million square miles in all. Now Sala and his team have set an even more ambitious goal: to see more than a third of the world's ocean conserved for the purpose not just of sustaining biodiversity but also of replenishing fish stocks and storing carbon.

FOR SALA, ONE OF THE MOST satisfying aspects of his job is collaborating with local communities in the places he and his team are seeking to preserve. At Pitcairn Island, a British overseas territory in the South Pacific, the Pristine Seas team worked closely with the island's 50 or so inhabitants, most of whom are descendants of the mutineers of the H.M.S. *Bounty,* the Royal Navy ship commandeered by members of its crew in 1789.

"We showed them an underwater world they had never seen," Sala recalls. "Huge schools of barracudas, clusters of giant clams, reef sharks swimming in some of the clearest waters ever measured in the Pacific. We said to them: 'This is one of the most pristine places on the planet, and it belongs to you. But it is at risk because of foreign fishing vessels that fish illegally in your waters. You have an opportunity to address that.'"

The Pitcairn Islanders began to see themselves as heroes of their own story, Sala says, and in 2015, at the islanders' request, the British government created a 322,000-square-mile marine reserve around Pitcairn and its uninhabited neighbors: Ducie, Oeno, and Henderson.

Far to the west of Pitcairn, in Micronesia, Pristine Seas worked with indigenous Palauans to give an ancient conservation tradition a modern twist. For centuries Palauans have used temporary fishing closures known as *buls* to preserve and rebuild their reef fish stocks. Over the years they created 35 reserves that protected marine life around their islands, some of which banned fishing permanently. Palau's president, Tommy Remengesau, asked Sala's team to compare the abundance of fish inside and outside the no-take reserves. They found that the species targeted by fishers were almost twice as plentiful within the no-take areas.

The team filmed their dives and screened the footage throughout Palau. "We wanted Palauans to see how well their traditional management works and that, as well as protecting their reefs, it benefits tourism," Sala says. In 2015 Palau's national congress established a no-take marine sanctuary covering 80 percent of the

Mangroves in shallow, murky waters near the shores of Isabela Island provide excellent nurseries for blacktip sharks. Some species of sharks lay eggs, but female blacktips produce four to 10 swimming pups per litter.

country's exclusive economic zone—an emphatic commitment to the idea that a flourishing economy depends on a healthy environment.

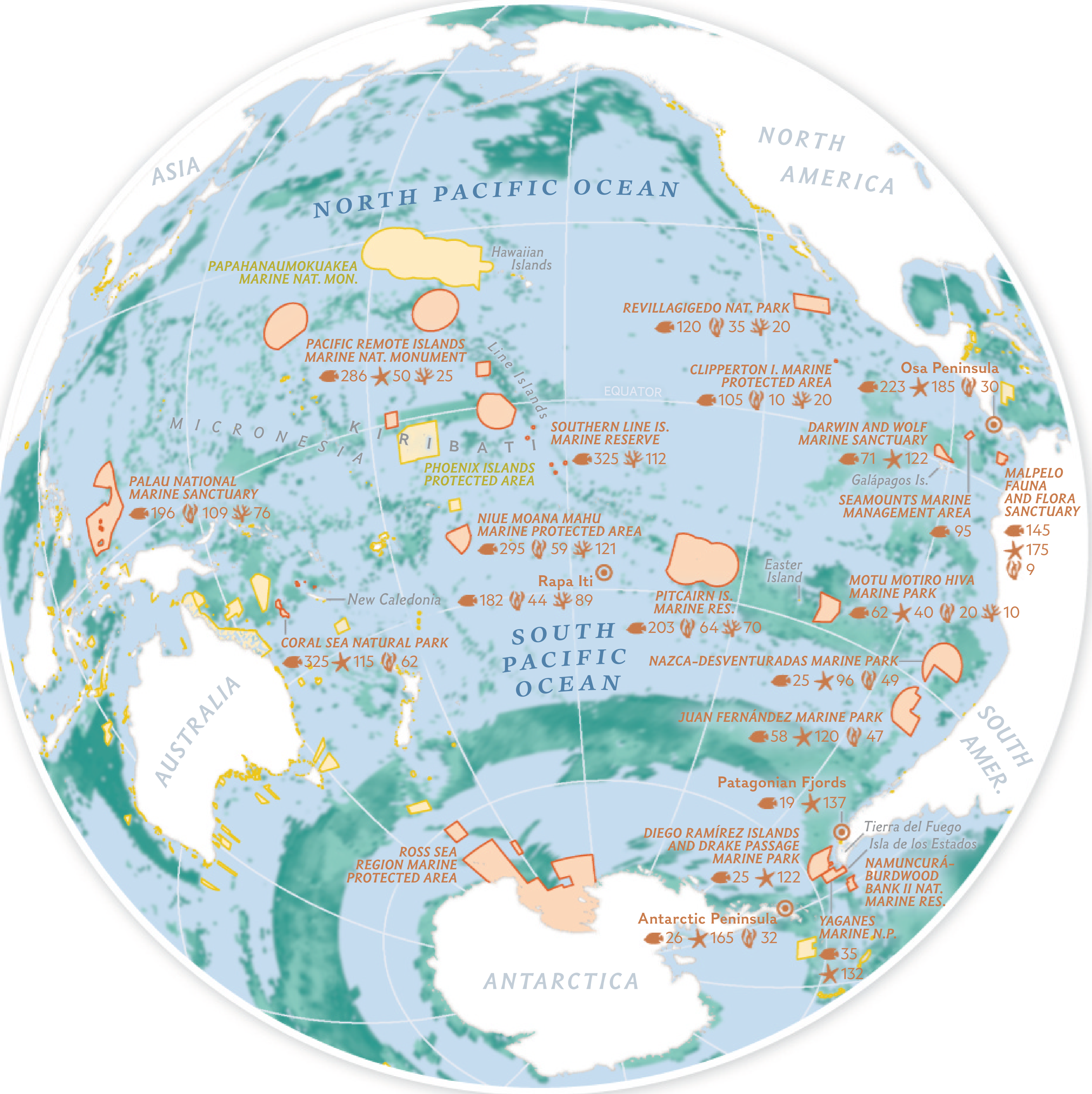
THAT TRUTH ISN'T UNIVERSALLY acknowledged. In most parts of the world, marine conservation is stymied by opposition from fishing, oil, and mining interests. A mere 7 percent of the world's ocean has any protection—mostly weak rules, with multiple exceptions—and only 2.5 percent is highly protected from exploitation. Outside of these zones, the ocean's story is one of continuing depletion. Each human generation grows up with a new normal, a lower baseline of marine diversity and abundance. Most people don't know what's been lost.

The loss is a result of disturbed or destroyed habitats, of overfishing, and of climate change that is both warming and acidifying the ocean. Pristine Seas is now reshaping its mission to address all three threats. With a network of no-take marine protected areas (MPAs), Sala believes, it's possible to benefit biodiversity, food security, and climate simultaneously.

The biodiversity benefit is self-evident—as it is on land, where parks and refuges protect thousands of threatened species. How MPAs benefit fisheries is less obvious. The common perception is that closing areas to fishing hurts fishing interests. But this perception is wrong, Sala argues.

The nonprofit National Geographic Society, working to conserve Earth's resources, helped fund this article.

Two giant manta rays feed on ocean plankton carried by the incoming tide at a reef in Palau. The country's protected areas sustain twice as many fish and five times the number of predatory fish as nearby unprotected areas.


ASIA
NORTH AMERICA
NORTH PACIFIC OCEAN
Hawaiian Islands
PAPAHANAUMOKUAKEA MARINE NAT. MON.
PACIFIC REMOTE ISLANDS MARINE NAT. MONUMENT
286 50 25
Line Islands
REVILLAGIGEDO NAT. PARK
120 35 20
CLIPPERTON I. MARINE PROTECTED AREA
105 10 20
Osa Peninsula
223 185 30
EQUATOR
MICRONESIA
KIRIBATI
SOUTHERN LINE IS. MARINE RESERVE
325 112
DARWIN AND WOLF MARINE SANCTUARY
71 122
Galápagos Is.
SEAMOUNTS MARINE MANAGEMENT AREA
95
MALPELO FAUNA AND FLORA SANCTUARY
145
175
9
PALAU NATIONAL MARINE SANCTUARY
196 109 76
PHOENIX ISLANDS PROTECTED AREA
NIUE MOANA MAHU MARINE PROTECTED AREA
295 59 121
Rapa Iti
182 44 89
New Caledonia
Easter Island
MOTU MOTIRO HIVA MARINE PARK
62 40 20 10
PITCAIRN IS. MARINE RES.
203 64 70
CORAL SEA NATURAL PARK
325 115 62
SOUTH PACIFIC OCEAN
NAZCA-DESVENTURADAS MARINE PARK
25 96 49
JUAN FERNÁNDEZ MARINE PARK
58 120 47
AUSTRALIA
SOUTH AMER.
Patagonian Fjords
19 137
Tierra del Fuego
Isla de los Estados
DIEGO RAMÍREZ ISLANDS AND DRAKE PASSAGE MARINE PARK
25 122
NAMUNCURÁ-BURDWOOD BANK II NAT. MARINE RES.
ROSS SEA REGION MARINE PROTECTED AREA
Antarctic Peninsula
26 165 32
YAGANES MARINE N.P.
35
132
ANTARCTICA

WHAT TO PROTECT NEXT

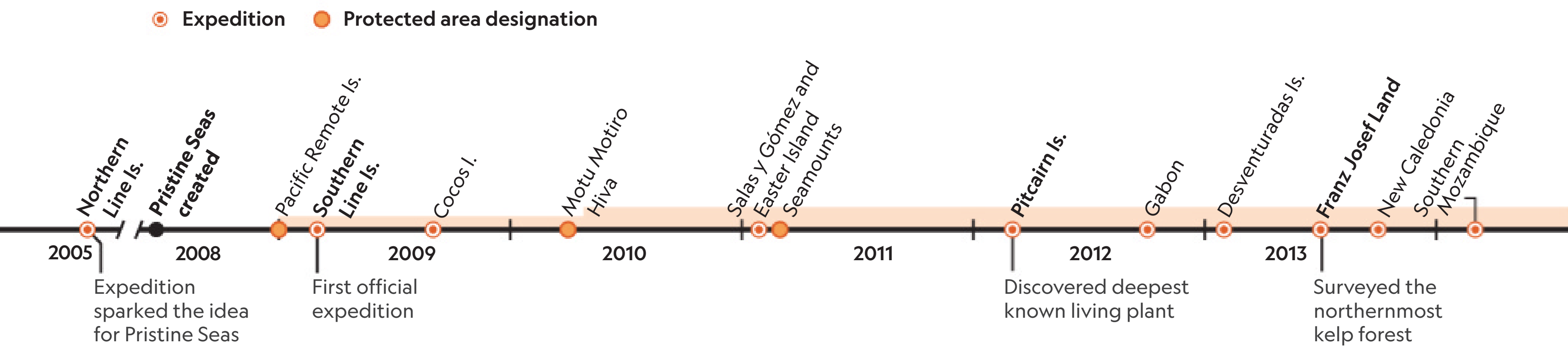
The National Geographic Society launched the Pristine Seas project in 2008 to explore and preserve the ocean. Pristine Seas has conducted 30 expeditions and helped create 22 marine reserves. Its new research indicates crucial areas to safeguard in the future.

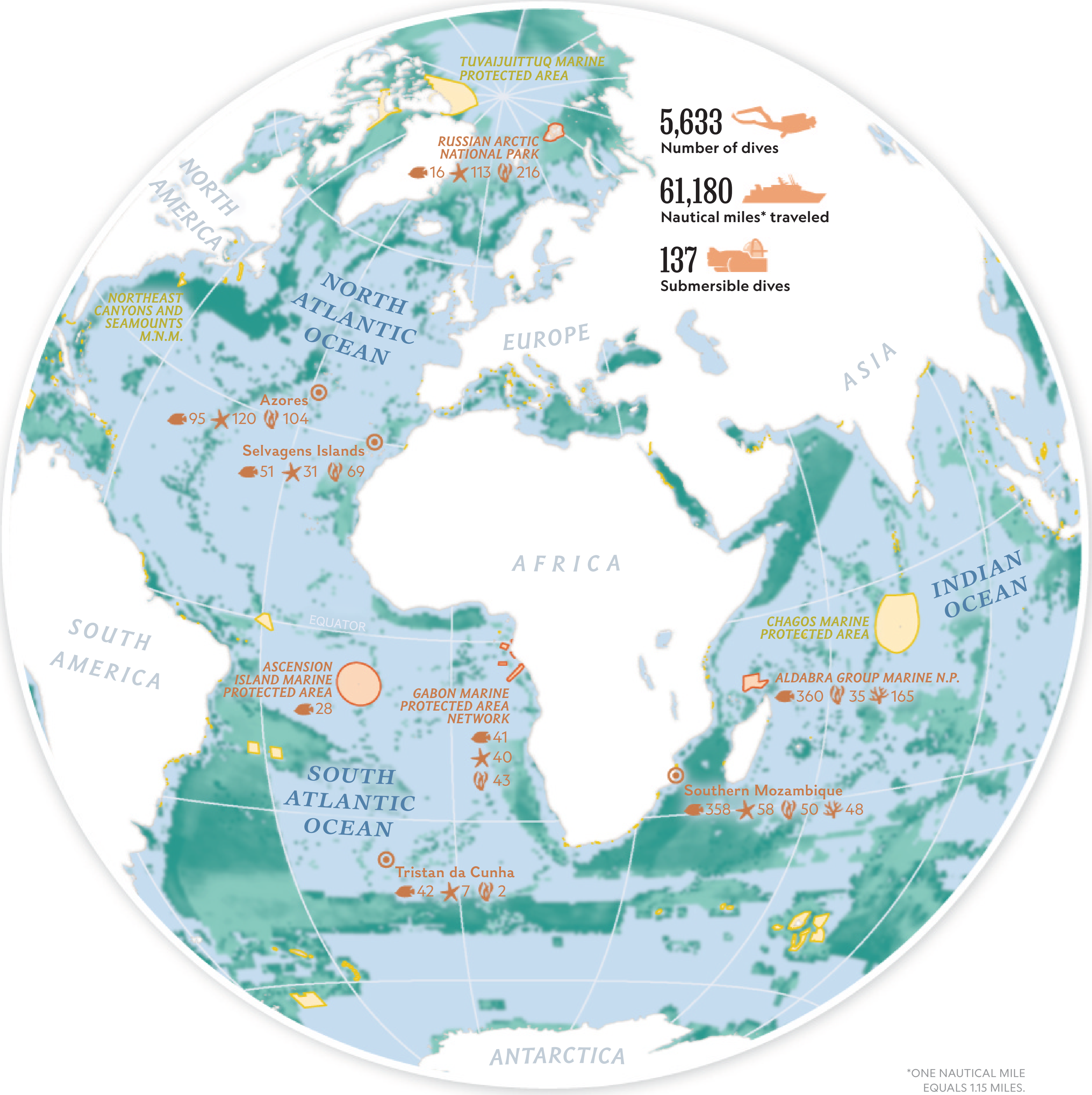
PRIORITY AREAS

Protecting 35 percent of the ocean (green areas) would benefit biodiversity, food production, and carbon storage. Dark green shading indicates top conservation priorities.

Lowest — Highest

🟦 Non-priority ocean




TUVAIJUITTUQ MARINE PROTECTED AREA
RUSSIAN ARCTIC NATIONAL PARK
16 113 216
NORTH AMERICA
NORTHEAST CANYONS AND SEAMOUNTS M.N.M.
NORTH ATLANTIC OCEAN
EUROPE
ASIA
Azores
95 120 104
Selvagens Islands
51 31 69
AFRICA
INDIAN OCEAN
EQUATOR
SOUTH AMERICA
ASCENSION ISLAND MARINE PROTECTED AREA
28
GABON MARINE PROTECTED AREA NETWORK
41
40
43
CHAGOS MARINE PROTECTED AREA
ALDABRA GROUP MARINE N.P.
360 35 165
SOUTH ATLANTIC OCEAN
Southern Mozambique
358 58 50 48
Tristan da Cunha
42 7 2
ANTARCTICA

5,633
Number of dives

61,180
Nautical miles* traveled

137
Submersible dives

*ONE NAUTICAL MILE EQUALS 1.15 MILES.

MARINE CONSERVATION

While 7 percent of the ocean has some form of protection, only 2.5 percent is highly protected from extractive activities.

- 🟧 Highly protected marine area affiliated with Pristine Seas
- 🟨 Other highly protected marine area
- ◉ Other Pristine Seas expedition site

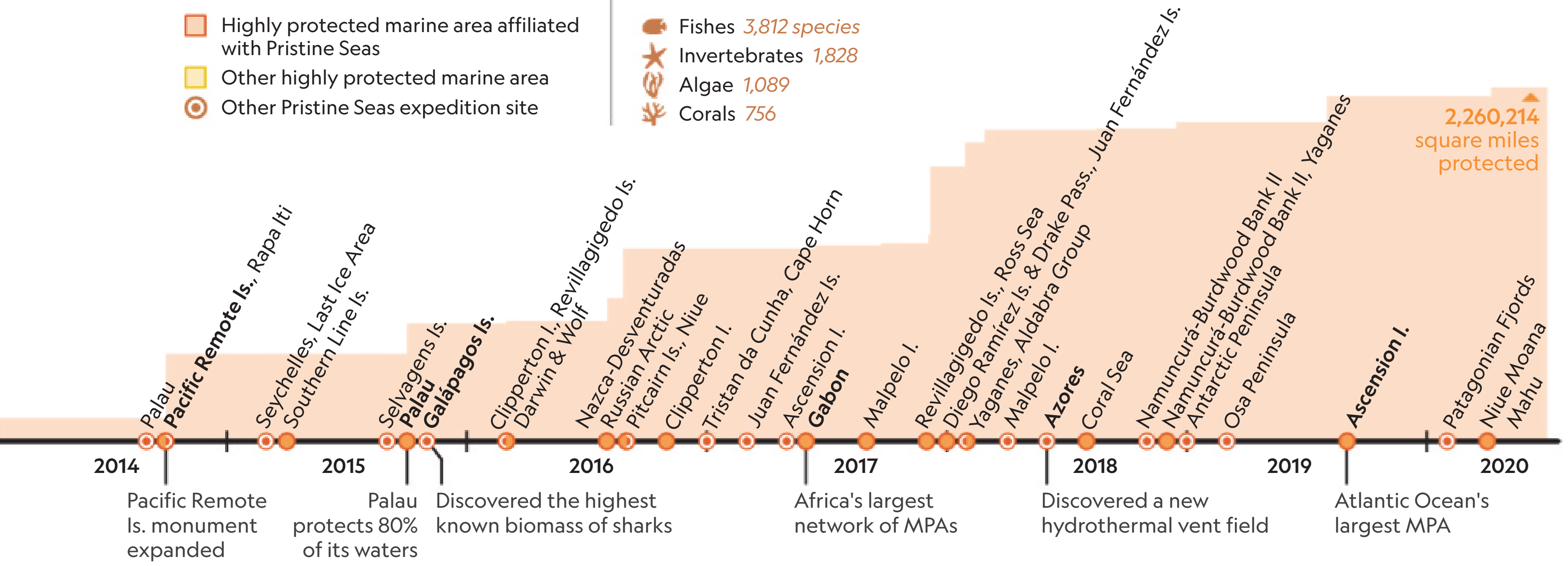
SPECIES SURVEYS

The team has measured the size, abundance, and biomass of more than 7,000 species so far.

- Fishes *3,812 species*
- Invertebrates *1,828*
- Algae *1,089*
- Corals *756*

CHRISTINE FELLENZ, TAYLOR MAGGIACOMO, AND IRENE BERMAN-VAPORIS, NGM STAFF

SOURCES: PRISTINE SEAS, NATIONAL GEOGRAPHIC SOCIETY; ENVIRONMENTAL MARKET SOLUTIONS LAB, UC SANTA BARBARA; TRISHA ATWOOD, UTAH STATE UNIVERSITY



Pacific Remote Is. monument expanded

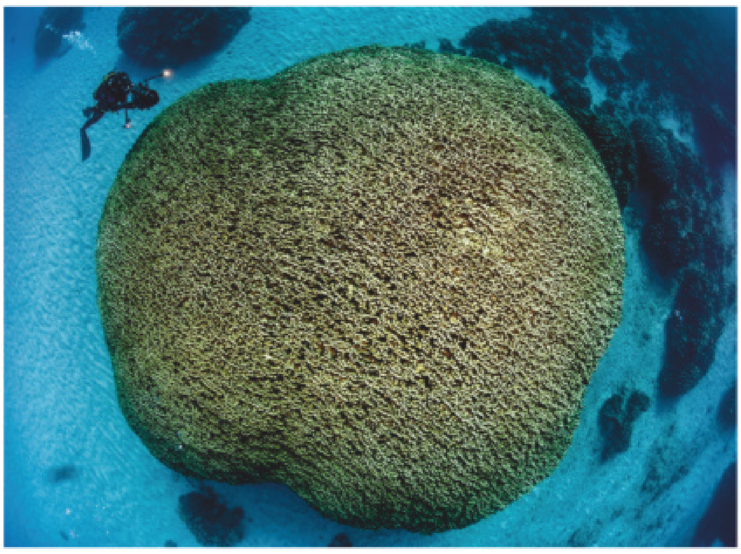
Palau protects 80% of its waters

Discovered the highest known biomass of sharks

Africa's largest network of MPAs

Discovered a new hydrothermal vent field

Atlantic Ocean's largest MPA



FIRST ROW

Southern king crab, Isla de los Estados, Argentina; sea whip goby on soft coral, Palau; sunset wrasse, Easter Island, Chile; octopus, San Ambrosio, Desventuradas Islands, Chile

SECOND ROW

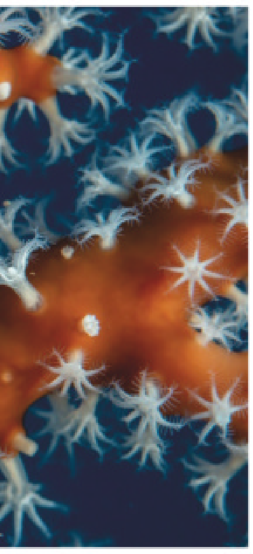
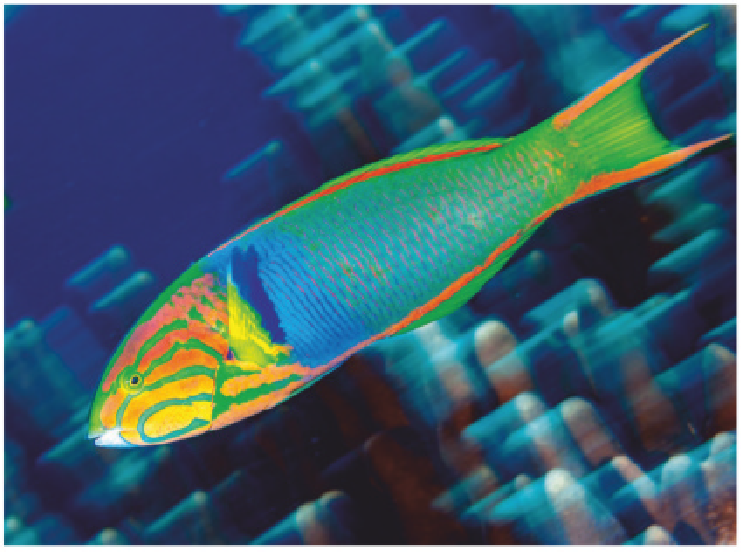
Green sea turtle, Cocos Island, Costa Rica; goldspot sea bream, Palau; squat lobster, Isla de los Estados; crosshatch triggerfish, Easter Island

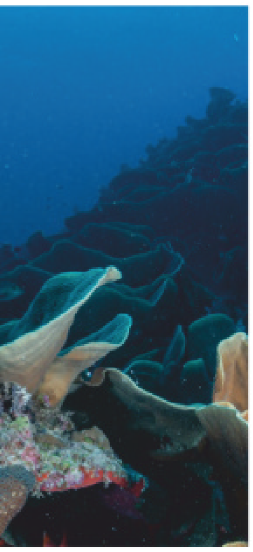
THIRD ROW

Pink anemonefish, New Caledonia; twinspot snapper, Palau; golden jellyfish, Jellyfish Lake, Palau; honeycomb moray on a bed of sun corals, Gabon

FOURTH ROW

Giant coral (unidentified), probably hundreds of years old, Easter Island; scalloped hammerheads, Cocos Island; black-sided hawkfish, Henderson Island, Pitcairn Islands; South American sea lion, Isla de los Estados



Bottlenose dolphins swim in Revillagigedo National Park, south of Baja California. At about 57,000 square miles, it's North America's largest fully protected marine reserve, home to silky sharks, hammerhead sharks, whale sharks, giant manta rays, tuna, and humpback whales.

"The fishing industry says we can't have more no-take areas because we need to catch more fish to feed nearly 10 billion people," the projected world population in 2050, he says. "But the worst enemy of fishing is overfishing."

The global fish catch has at best plateaued since the mid-1990s—some researchers say it has actually declined—even as the fishing industry has increased its efforts to catch fish. The reason is that so many fish stocks are depleted and need a chance to rebuild. "Protected areas are not the enemy of fishing," Sala says. "Our analysis shows that protection of the ocean can produce a net benefit to fishing."

A case in point is what happened to the Hawaiian tuna longline fishery in the wake of the creation and expansion of two U.S. protected areas in the Pacific. The Papahānaumokuākea Marine National Monument and the Pacific Remote Islands Marine National Monument are among the largest MPAs on Earth; together they're roughly four times the size of Texas. They provide a haven for corals, fish, birds, sharks, and whales. But because they exclude commercial fishing in what amounts to about a quarter of the entire U.S. exclusive economic zone, fishers argued against them. Some researchers have found, however, that there has been no lasting economic harm to the local fishing industry.

It may seem counterintuitive, but the more fully an area is protected, the greater the benefit to fishers operating outside its boundary—an outcome that has been documented in species ranging from tuna to lobsters to clams. Fully protected marine reserves, Sala says, are like an investment account with an untouched principal: They provide yearly returns in the form of adult and larval fish and invertebrates that spill out of the reserves and replenish the stocks that fishers target.

Still, MPAs are only as secure as the political will to maintain them—including in the U.S., where President Trump has stated that he is inclined to open the nation's only Atlantic marine national monument to commercial fishing.

The climate benefit of MPAs arises because carbon dioxide is the main greenhouse gas in the atmosphere and marine sediments are one of Earth's main carbon reservoirs, storing more carbon than soils on land. Undisturbed sediments can lock up carbon for thousands of years. When sediments are disturbed by bottom

Atlantic walruses feed and rest in a shallow passage on Northbrook Island in Franz Josef Land. The archipelago was added to the Russian Arctic National Park in 2016 to protect species such as polar bears, bowhead whales, ivory gulls, and Atlantic walruses. The walruses were on the brink of extinction by the 1900s because of hunting; now there are more than 10,000.

trawling or seabed mining, the stored carbon is released back into circulation.

Just as there's more than one reason to save a forest, there's more than one benefit to protecting the ocean, and that makes the case for doing so more compelling. "We cannot think of biodiversity in isolation anymore," Sala says, "and we cannot think of climate in isolation. It will be impossible to achieve the goals of the Paris climate agreement"—to keep global warming from exceeding the widely accepted disaster threshold of two degrees Celsius, or 3.6 degrees Fahrenheit—"unless we have a significant proportion of the planet in a natural state."

How large a proportion? Sala and his team calculate that a 14-fold expansion of the fully protected part of the ocean, from 2.5 percent to 35 percent, would provide 64 percent of the biodiversity benefits and shield 28 percent of vulnerable carbon while increasing the global fish catch by almost 10 million metric tons. If instead of pursuing strictly national priorities, countries cooperated to set aside the most strategic areas of the ocean, they could achieve the same results by protecting less than half as much area.

Even that may sound impossible. But the alternative is dire. Do we want to keep writing and reading marine obituaries, or do we want our children to inherit an abundant, flourishing ocean? For now, we still get to choose. ☐

Author **Kennedy Warne** has written about the sea for *National Geographic* since 2002. Photographer **Enric Sala** is a National Geographic Society explorer-in-residence.

Dominik Lubecki practices flipping over a bench in Nowy Port, a working-class district where dockhands in 1946 launched one of the first communist-era strikes demanding better working conditions. When he's not skateboarding or composing hip-hop, "Lulek" works as a volunteer with Gdańsk's youth.

POLAND DRAWS INSPIRATION FROM THE CITY THAT GAVE BIRTH TO THE SOLIDARITY MOVEMENT 40 YEARS AGO.

WAITING FOR GDAŃSK

BY **VICTORIA POPE** PHOTOGRAPHS BY **JUSTYNA MIELNIKIEWICZ**

DOR 20T

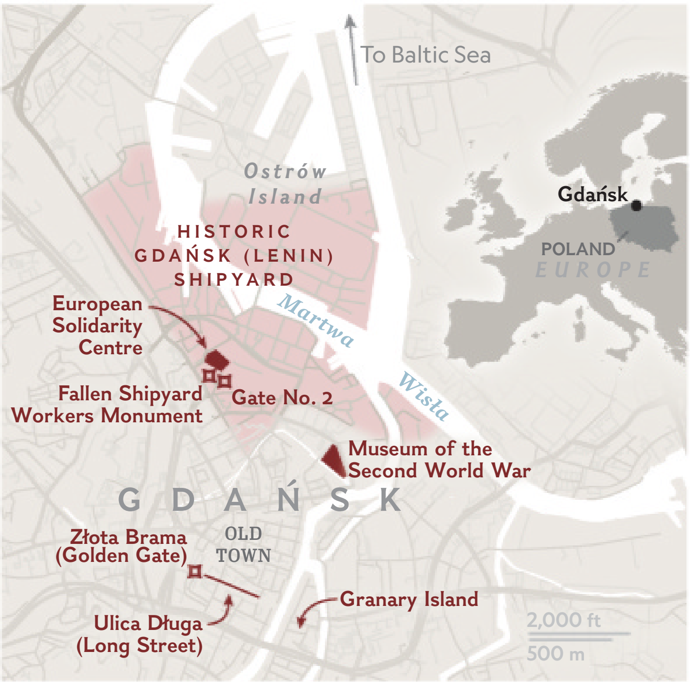
In communist times, the Gdańsk Shipyard employed as many as 20,000 workers and was the birthplace of Solidarity, the country's first independent trade union. Smaller shipyards now manufacture luxury yachts as well as towers for wind turbines.

FOR THE LONGEST TIME, I ASSOCIATED THE CITY OF GDAŃSK WITH MY POLICE DETENTION. IT WAS DECEMBER 16, 1982, AND A YEAR EARLIER THE COMMUNIST AUTHORITIES HAD IMPOSED MARTIAL LAW.

A women's march, called Manifa, wound through Old Town this spring, highlighting feminist and environmental concerns with the slogan "Women and Earth have too much to bear." Gdańsk, with its multicultural history, has long fostered progressive social movements.

They were signaling an easing of restrictions by releasing the Solidarity trade union leader Lech Wałęsa after 11 months of internment. A government spokesman smugly described him as "the former head of a former union." Wałęsa was due to give a speech that day, and about 40 of us—foreign correspondents, photographers, and our Polish assistants—were clustered next to the entrance to his apartment block, expecting to go inside for an interview.

Instead, police barred us from entering. Because Solidarity was banned at the time, Wałęsa's speech and our attempt to see him were deemed illegal. The face-off was at first alarming—many Poles had been imprisoned during the crackdown. But the tension gave


To Baltic Sea
Ostrów Island
HISTORIC GDAŃSK (LENIN) SHIPYARD
European Solidarity Centre
Fallen Shipyard Workers Monument
Gate No. 2
Martwa
Wisła
Museum of the Second World War
GDAŃSK
Złota Brama (Golden Gate)
OLD TOWN
Ulica Długa (Long Street)
Granary Island
2,000 ft
500 m
Gdańsk
POLAND
EUROPE

SOREN WALLJASPER AND SCOTT ZILLMER, NGM STAFF
SOURCE: ANNA MYDLARSKA, EUROPEAN SOLIDARITY CENTRE

way to comic relief. You see, I was four months pregnant, and particularly the Poles in our group were outraged that the police would subject me to any stress, much less detention—and they let the officers know it. Soon it seemed that half the apartment complex had heard I was with child. Women stopped to bawl out the police, who accepted this dressing-down with quiet embarrassment. In those times few Poles felt friendly toward the authorities, and it must have been cathartic to lecture these representatives of power on proper Polish behavior. Still, we were crammed into windowless vans and transported to the station. There we were merely warned to stay away from Wałęsa and released.

Now I am back in Gdańsk. It's been 40 years since the August shipyard strikes that birthed the Solidarity movement, setting Poland on the road to democracy. Those strikes drew journalists like me to the country to cover the peaceful revolution. Based in Warsaw for three years, I reported on the rise of the 10 million–strong union. While on a fellowship in 1989 I chronicled the compromise between the opposition and the communist party that led to partially free elections—and a landslide victory for Solidarity. The country has since adopted a new constitution, protecting the independence of the judiciary and other institutions, but the present government is widely seen as undermining these democratic foundations.

In this Baltic seaport, with a history of trading goods, people, and ideas dating to the Middle

Lech Wałęsa, a shipyard electrician, became the leader of Solidarity in 1980, winner of the Nobel Peace Prize in 1983, and president of Poland in 1990. Now 76 years old, he remains engaged in politics, demanding that the government respect the constitution.

Ages, perhaps not revolution but certainly rebellion is still alive. The city has defied the ruling Law and Justice party and gained a reputation for tolerance. When Poland refused to accept refugees as part of the European Union resettlement plan, Gdańsk said it would welcome them. And when the leader of the ruling party, Jarosław Kaczyński, called LGBT ideology a threat to Polish identity and a "massive storm of evil," city officials vowed to protect sexual minorities.

IF GDAŃSK IS THE OPPOSITION CITY, the European Solidarity Centre is its heart. It's a living monument to the trade union and the legacy of the strikes, which ended nearby at the historic Gate No. 2 to the Gdańsk Shipyard, also known then as the Lenin Shipyard. Wałęsa has an office on the second floor. When I meet with him, he's wearing a gray shirt emblazoned with the word KONSTYTUCJA. He has many versions of this shirt and even wore one to President George H. W. Bush's state funeral. Its message: The ruling party has trampled basic constitutional rights. The state-controlled media has choice words for Wałęsa too, depicting him as a traitor and a has-been.

After cordial greetings, Wałęsa deepens his voice and briskly says, "*Pierwsze pytanie*"—first question—as if he's pressing a stopwatch to begin a race. Does he have somewhere to go, or is it simply a way of taking command? But he patiently responds when I ask about the moment he entered the shipyard on August 14, 1980. He recalls it as "a certain stage, a certain moment," adding, "I expected it wasn't the last stage in my fight." In his negotiations, he tells me, "as I knew that I wasn't going to win too much, I was trying to act so as not to lose too much."

At one point during our conversation, I interject with a friendly wisecrack: "I know you weren't on a motorboat." It's a reference to allegations he showed up in a military boat after the strike was under way. The claim, made by some of his critics, seeks to prove police collaboration. Wałęsa limits his rebuttal to a roll of his eyes.

We go back to the meaning of his shirt. He suggests Poland fits a global trend toward declining democratic values. He singles out laws that the ruling party pushed through parliament curbing the independence of the courts. "For me also, the judicial system and other actions were an obstacle," he admits, recalling the challenges he faced when he was president from 1990 to 1995. But he says he didn't try to "liquidate" the independent judiciary. "Once you eliminate one obstacle, then you need to eliminate the next obstacle. That's how dictatorships emerge."

GDAŃSK IS BOTH GRIT AND ELEGANCE. Around the port's industrial zone, the skyline is a tangle of cranes, lifting hooks, and smokestacks. Here and there, pockmarks left from World War II are visible on facades. In the city center, however, the skyline is a pristine panorama of church spires, towers, and red-tile roofs. The streetscape, too, is marvelously Old World, thanks to a painstaking postwar reconstruction effort.

Ulica Długa, the main pedestrian walkway, is rightfully considered the crown jewel. The street is lined with rebuilt 16th- and 17th-century Flemish-style buildings with ornate gables topped with sculptures, urns, and finials. They are suitably grand for the Dutch merchant princes and others who made fortunes shipping grain. For centuries, Gdańsk—or Danzig, as it was called for most of its history—was a cosmopolitan and prosperous city. As a member of the Hanseatic League, a trading alliance that began in the 12th century, it was linked to ports as disparate as London and Novgorod.

Nearby is the famous Złota Brama, the Golden Gate, built in the first part of the 17th century and reconstructed after it was destroyed in World War II. With its huge two-story windows and classical columns, it's eye-catching, but I am headed for a simple, black marble plaque,

MARK HENLEY, PANOS PICTURES

set in the pavement nearby. It reads, "Gdańsk is generous. Gdańsk shares its good. Gdańsk wants to be a city of solidarity"—words spoken by Mayor Paweł Adamowicz moments before he was savagely stabbed in this area in front of an audience of hundreds in January 2019, an assault that killed him. The attacker had a history of violent crime, but to many in Gdańsk, the assassination reflected the febrile political climate that pitted their city's vision of openness against the aggrieved nationalism and vitriol of the ruling party.

"Our situation here is so sharp right now," says Julia Borzeszkowska, a 20-year-old first-year law student at Gdańsk University. "The violence and hate is so strong that it pushed someone to murder another person." In her last year of high school, Borzeszkowska organized a protest called March Beyond Divisions, which drew 1,500 young people into the streets.

As she peers out from oversize wire-rimmed eyeglasses, Borzeszkowska's direct, blunt words belie the quavering in her voice. "My generation was raised believing in freedom, solidarity, and fighting for democracy. We learned this from our parents and grandparents. These issues were important to them, and they are important for us right now." She speaks with utter conviction, and I am reminded of the forthrightness of the early Solidarity activists. May I use your name? I would ask, and usually the answer would be yes, despite the danger. I was told more than once: I want my children to know what I stood for.

Borzeszkowska vows she will return to activism, and I believe her.

The mayor's murder also brought thousands of people to the streets in Gdańsk and Warsaw. Aleksandra Żurowska—a prominent Gdańsk physician who, with her daughter Joanna Lisiecka-Żurowska, introduced me to people in the city—recalls the outpouring of grief. Friends from all over Poland called to commiserate. "They were telling me: We are looking at what's happening in Gdańsk, and we are waiting again. Always Gdańsk leads us in these moments."

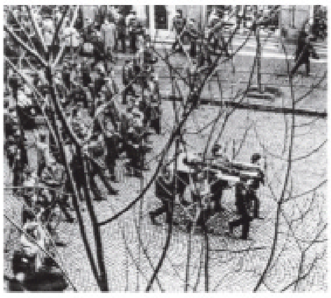
Though the assassination was 14 months before my visit, the subject comes up often, even in casual exchanges. It's clearly seen as a moment of reckoning for the city and its ideals. "In my daily life I do not dwell on that horrible Sunday," says the current mayor, Aleksandra Dulkiewicz, who also supports progressive causes and welcoming non-Poles. Now many

POLAND'S POSTWAR PATH

From a communist Soviet satellite to a new democracy, the Eastern European country has had a tumultuous postwar history.

JANUARY 1947

In the aftermath of World War II and Soviet occupation, the Polish communist party takes power in a fraudulent election.



DECEMBER 1970

Demonstrations and strikes against price hikes break out in Gdańsk and spread to other Baltic coast cities. At least 40 people are killed and more than a thousand wounded.

OCTOBER 1978

Karol Józef Wojtyła, the archbishop of Kraków, becomes Pope John Paul II. His 1979 visit to Poland rallies millions of the disaffected.

AUGUST 1980

Led by Lech Wałęsa, workers at the Gdańsk Shipyard go on strike. By the end of the month, authorities recognize the Solidarity trade union.

DECEMBER 1981

Backed by the Soviet Union, Poland's leader declares martial law. Wałęsa and other dissidents are arrested.

OCTOBER 1982

Solidarity is banned.

JULY 1983

Martial law is lifted.

FEBRUARY 1989

Talks between the government and the still-banned Solidarity lead to the union's legalization, the formation of a Senate, and the creation of the office of president.

JUNE 1989

Solidarity wins all but one of the contested seats in the parliamentary election.

MARCH 1990

Mikhail Gorbachev is elected president of the Soviet Union. He spearheads reforms, which reverberate throughout Poland and Eastern Europe.

DECEMBER 1990

Wałęsa wins the newly established presidency in Poland.

NOVEMBER 1995

In a close election, Wałęsa loses the presidency to a former communist.

JUNE 2003

In a referendum, Poles vote to join the European Union.

SEPTEMBER 2005

The socially conservative Law and Justice party comes in first in the general elections.

OCTOBER 2007

The largest opposition party, the liberal Civic Platform, wins in early general elections.

MAY 2015

Law and Justice wins a majority in parliamentary elections.

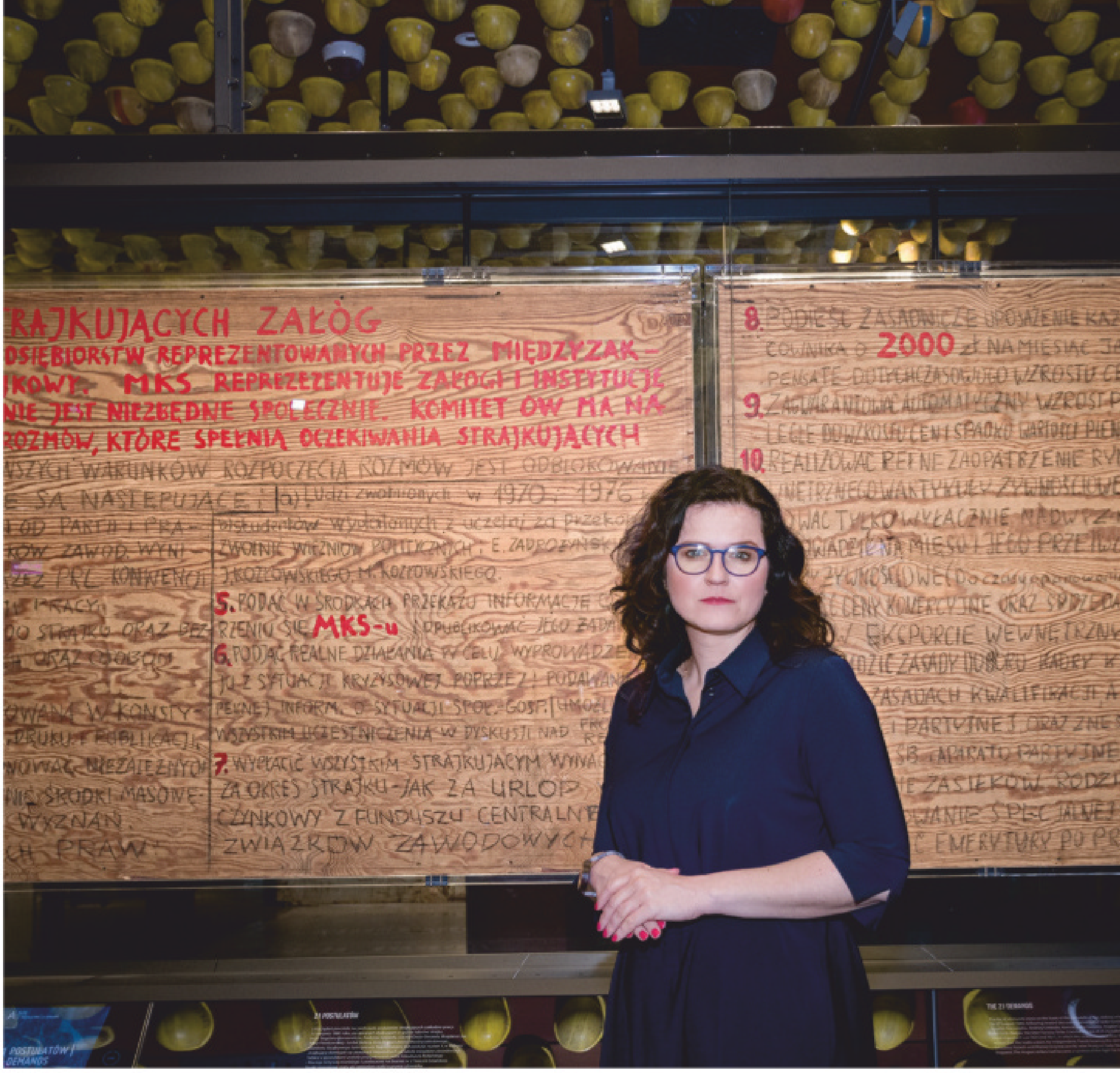
JULY 2017

Large demonstrations protest legislative proposals that are seen as endangering the independence of the judiciary.

JANUARY 2019

Gdańsk's mayor, Paweł Adamowicz, is assassinated. Some see his death as a result of rising intolerance encouraged by the Law and Justice party.

PHOTOS (FROM TOP): EDMUND PEPLINSKI, FORUM, ALAMY STOCK PHOTO; WOJCIECH KRYNSKI, FORUM, ALAMY STOCK PHOTO; PETER MARLOW, MAGNUM PHOTOS; WOJCIECH STRÓŻYK



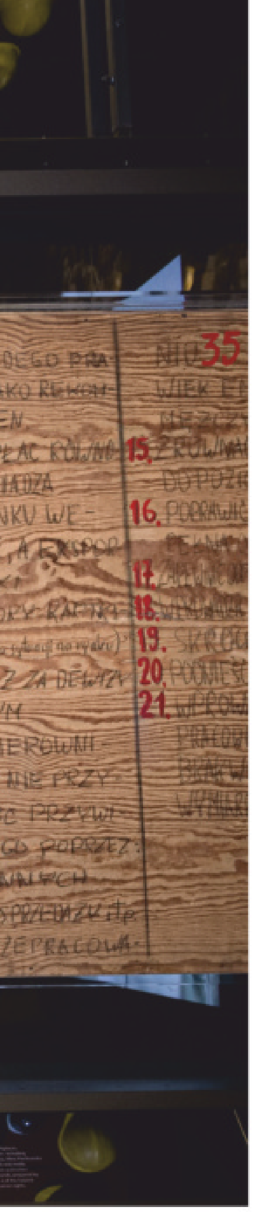
CLOCKWISE FROM TOP LEFT

The mayor of Gdańsk, Aleksandra Dulkiewicz, stands before the 21 demands written by activists on plywood panels and displayed during the 1980 strike at the Gdańsk Shipyard. The former deputy to a mayor who was murdered, she won a landslide victory in 2019.

Gdańsk figures large in World War II history as the site of the Battle of Westerplatte. In September 1939, Nazi Germany launched its invasion of Poland with an attack on a garrison in the city's harbor. Despite damage to the barracks, defenders held on for seven days.

Jerzy Bohdan Szumczyk created his mobile sculpture "SOS" as a protest against the destruction of historic shipyard buildings and cranes in an area slated for renewal.

A group of young acolytes serve at a Mass at St. John's Church. Altar girls are still an exception in Polish Catholic churches. The church's pastor, Krzysztof Niedałtowski, is a well-known social activist.



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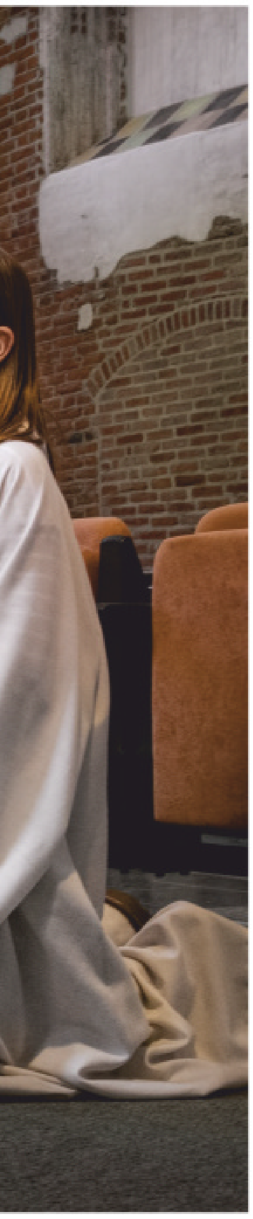


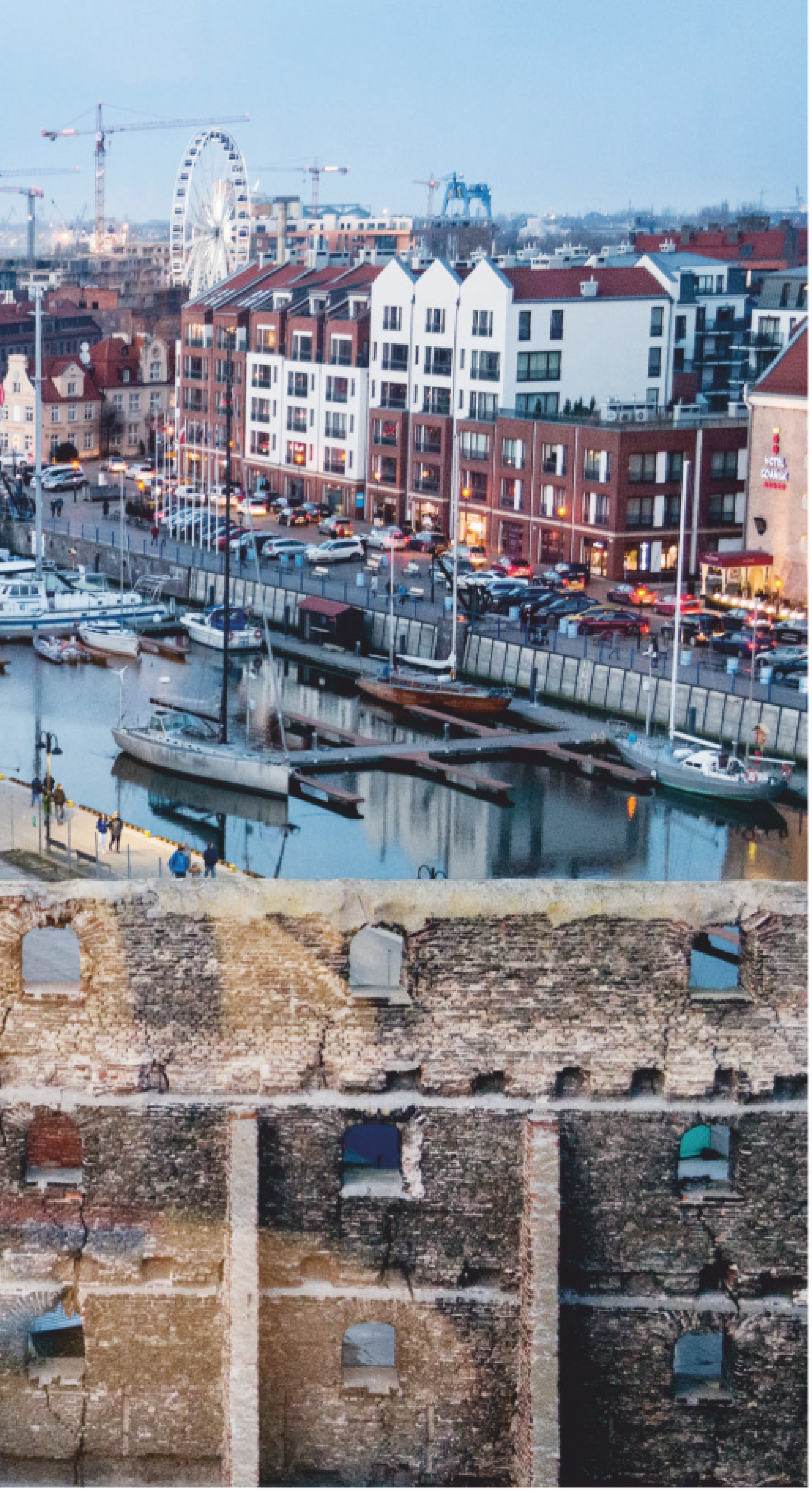
In this view from Granary Island, renovated buildings mix with modern ones on the banks of the Motława River. The island was once a shipping hub of this Baltic seaport, where hundreds of warehouses stored grain. Most of the historic buildings were destroyed during World War II, but some of the ruins are being restored as the island is redeveloped.

towns and cities in Poland follow what's called the Gdańsk model of integrating foreigners. That embrace of newcomers—of 460,000 citizens, about 25,000 are immigrants from the former Soviet Union, Rwanda, and Syria—is consistent with the city's past, notes Aleksander Hall, a historian and Gdańsk native.

"One unique aspect of Gdańsk was that it was always a multicultural city," he explains. As a port, it was a freewheeling commercial hub, welcoming traders and other foreigners from many countries, particularly Germans, but also Scots, the Dutch, and the English. During Gdańsk's Reformation in the 1600s, it sheltered persecuted religious groups—Dutch Mennonites as well as Huguenots and Jews. Because of the city's growing ethnic mix, that heritage is being reborn, Hall says.

THERE IS A FAMOUS LINE from a novel by William Faulkner that I first learned in Poland, when a journalist friend, Jacek Kalabiński, quoted it to explain why Poles seem fixated on painful chapters of their history. "The past is never dead. It's not even past." Those sentences run through my head as I learn about state efforts to control the historical narrative in Gdańsk. The city's World War II museum had its founding director and curators pushed out by the Ministry of Culture, which objected that the exhibits were "not Polish enough."

Lisiecka-Żurowska and I talk about the war



while traveling on the train to Gdańsk. She grew up there, and her family story speaks to the complexities of the conflict as it played out in her hometown. On the eve of the war, the city was predominantly German-speaking but had an established Polish community. It had received special status as a free city after World War I; Poles were given control of the railways and access to the port. On September 1, 1939—the start of World War II—a German battleship fired on a Polish garrison, which held out for seven days despite being outgunned. Lisiecka-Żurowska's great-grandmother's husband and three brothers, members of the educated elite, were arrested and sent to concentration camps, where they died.

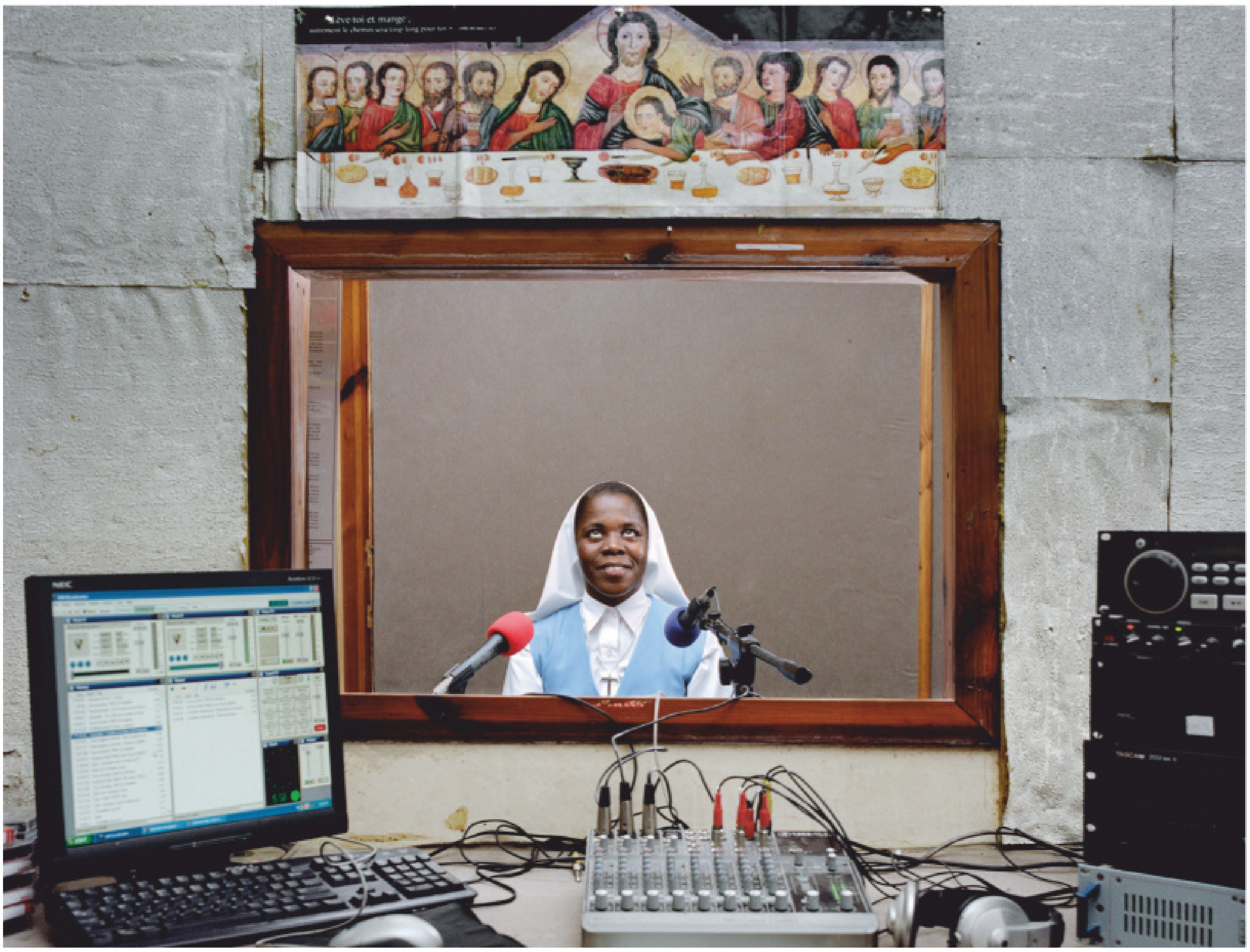
By the end of the war, most of the city lay in ruins. What was left of the German population fled or was expelled. Poles were forcibly removed from areas such as Ukraine (annexed by the Soviet Union) and resettled around Poland. People in search of jobs—Wałęsa told me most were ambitious youth who felt suffocated by small-town life—flocked to Gdańsk to work in the shipyards and other industries. Wałęsa's wife, Danuta, recalls turning to her mother before boarding a bus leaving her village and blurting out, "I will not come back here."

That fierce determination is still part of Danuta Wałęsa, though she endured many unhappy years when her husband was battling the authorities. A friend of a friend arranges a meeting, and we sit at the dining room table in her light-filled family home. I remind her that we'd met in the days when the old apartment was jammed with visitors waiting for a word with Lech. I mention that I always tried to greet her, but she often seemed out of sorts, even angry. She's shaken by my comment, and her eyes well with tears. She had six children at the time of the shipyard strikes and felt isolated and alone. "I don't know how I had the strength to survive all this," she tells me.

But she more than survived. In 2011 she published a best-selling memoir that described a hollowed-out marriage. Nonetheless, she's protective of her husband and condemns the ruling party's attacks on him. "It is absolutely outrageous," she says. "This government doesn't recognize him, and they want to say he is nobody." Seeing the flash of anger in her eyes, I'm reminded of the women at the apartment complex and their feisty defense of a pregnant woman.

Danuta believes the country is ripe for change, but fears there isn't a leader to rally the opposition. "The country needs a second Wałęsa," she says. And not just a second Wałęsa, she underscores, but one with a strong core of supporters and advisers like her husband had when he fought the communist regime. Though she warns of dangers ahead—"We need to stand up like before, or something terrible will happen"—she's confident that when change does come, it will be her city that leads: "There is no braver place in Poland than Gdańsk." □

Victoria Pope was a foreign correspondent in Warsaw, Bonn, and Moscow, and an editor at this magazine. **Justyna Mielnikiewicz** was born in Poland and is now based in Tbilisi, Georgia.



INSTAGRAM

PAOLO WOODS

FROM OUR PHOTOGRAPHERS

WHO

Woods is a Dutch-Canadian documentary photographer based in Italy.

WHERE

Les Cayes, a city in southwest Haiti

WHAT

A Hasselblad medium format film camera with a 50mm lens

Woods lived for several years in Haiti, where many people may not read or have access to television or the internet but radio is ubiquitous. In the city of Les Cayes, Woods spent months photographing radio programs' hosts. One of the most popular, Sister Melianise Gabreus broadcast a daily advice show on 95.5 FM, the Roman Catholic diocese's channel. She was shy at first, says Woods, but posed for this 2013 photo when "I told her many of her faithful listeners would be very happy to see what she looks like."

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Iberian Grey Shrike *(Lanius meridionalis)*

Size: Body length, 24 - 25 cm (9.4 - 9.8 inches) **Weight:** 48 - 93 g (1.7 - 3.3 oz) **Habitat:** Dry, warm, sunny lowlands **Surviving number:** Estimated at 744,300 - 1,312,300 mature individuals

Photographed by Eduardo Blanco

WILDLIFE AS CANON SEES IT

A warning or a gift? Both aims are achieved when the Iberian grey shrike impales prey on thorns or barbed wire. These grim displays mark territory and are also a pair bonding gift from the male to the female. Once their chicks have hatched, both parents hunt to provide for the family, searching out insects and small vertebrates like lizards and mice. But agricultural development is removing the trees and shrubs it needs, while also introducing herbicides and pesticides, which kill the shrike's main prey.

As Canon sees it, images have the power to raise awareness of the threats facing endangered species and the natural environment, helping us make the world a better place.

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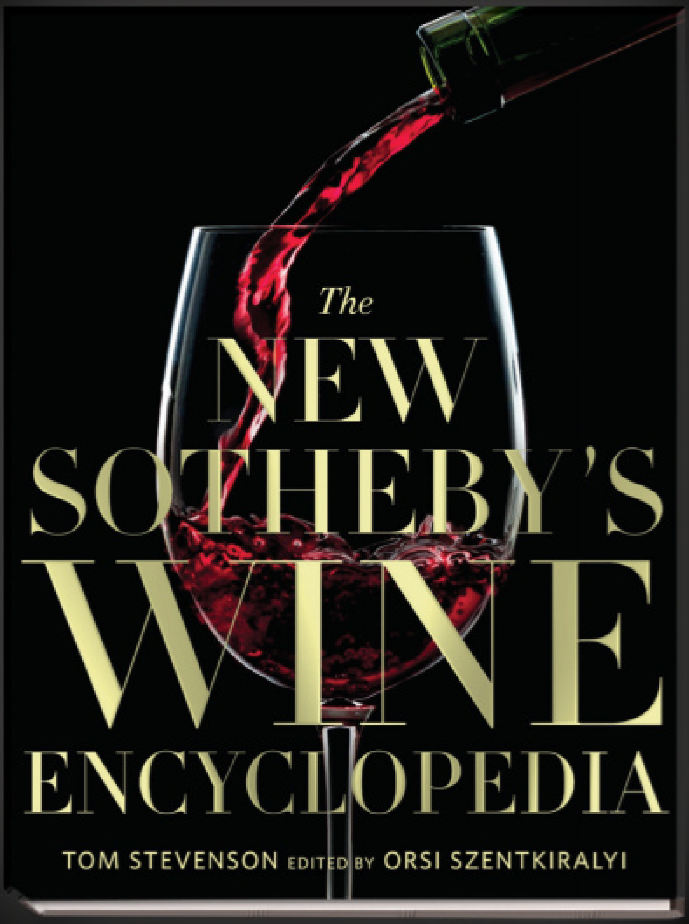
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